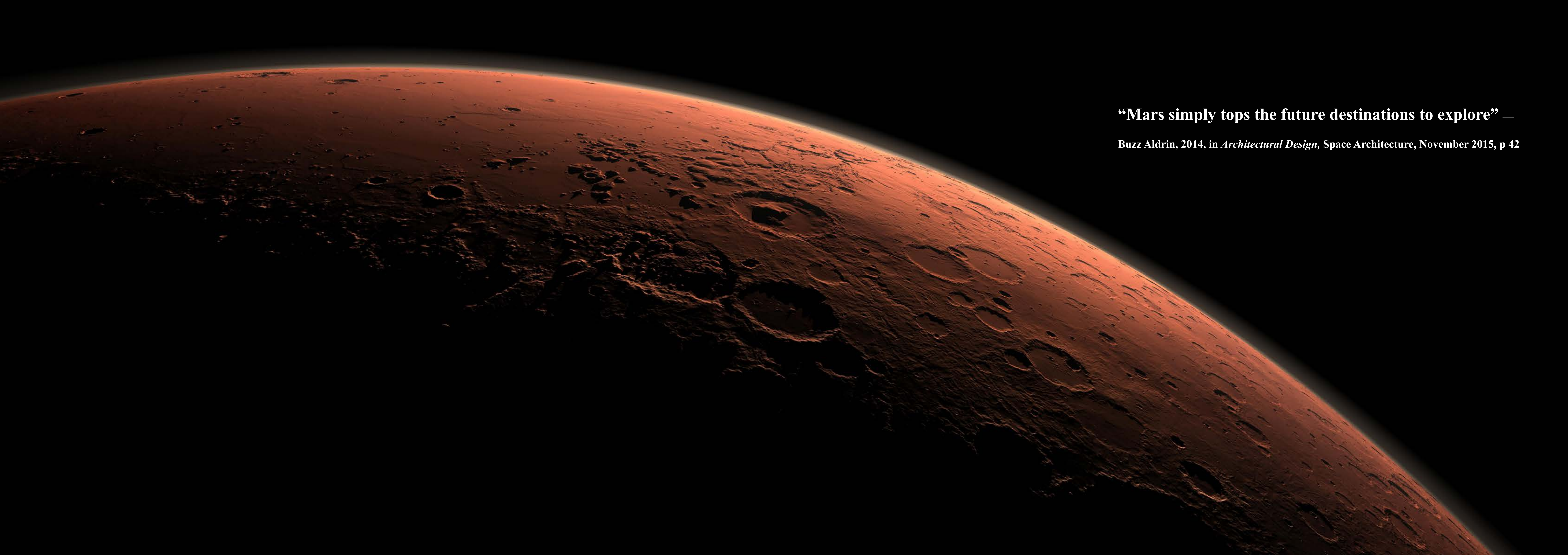
A LIFE ON MARS



“Mars simply tops the future destinations to explore” —

Buzz Aldrin, 2014, in *Architectural Design,* Space Architecture, November 2015, p 42

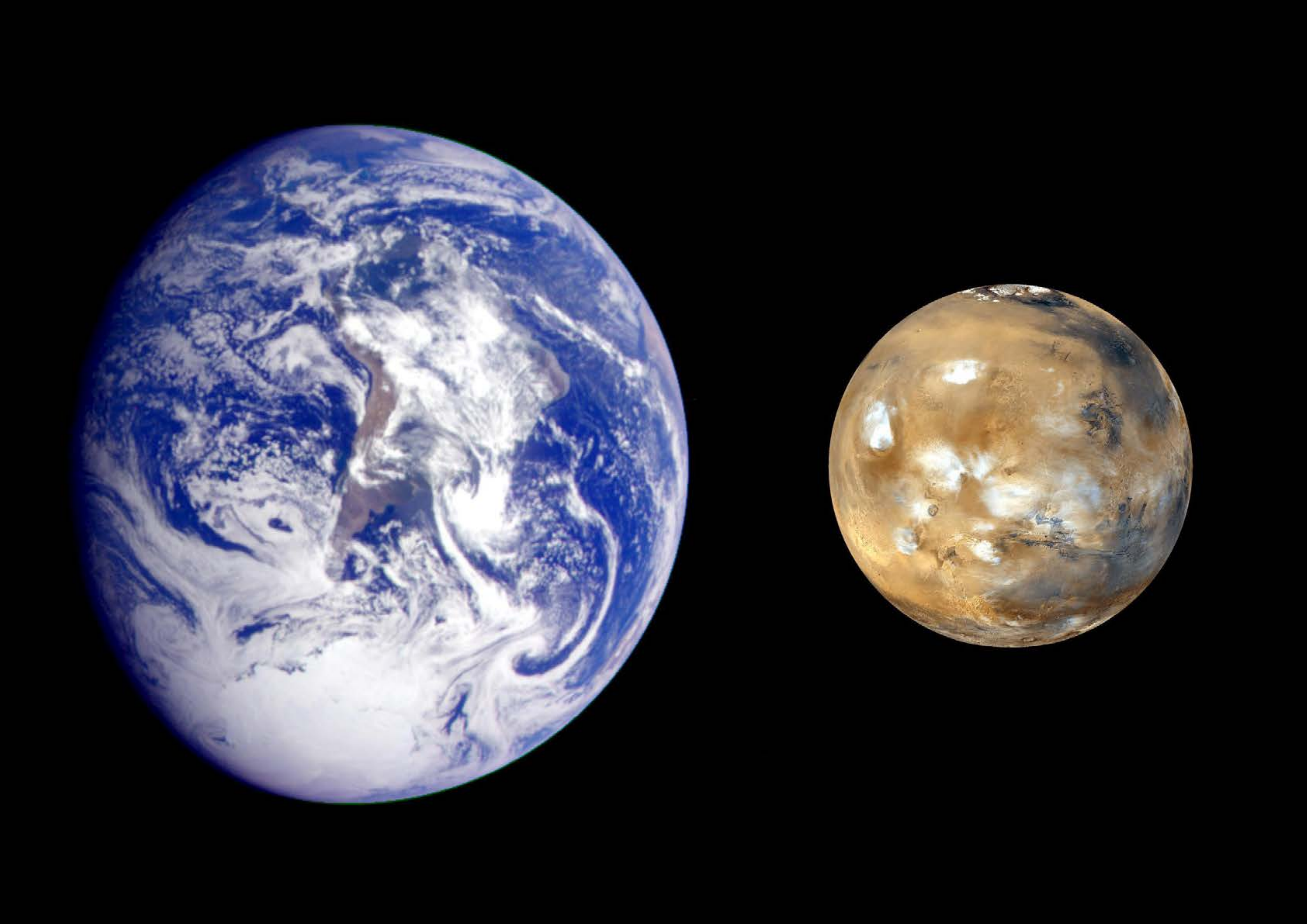


Figure 1 - *Front Cover Image*
Figure 2 - *Previous page - Daybreak at Gale Crater*
Figure 3 - *Image page left - Earth compared to Mars.*

A Life On Mars

An architectural research project into the creation of a permanent human presence on the surface of Mars.

Explanatory Document

A Research Project submitted in partial fulfilment of the requirements of the degree of

Master of Architecture (Professional). Unitec Institute of Technology, 2015.

Ravi Solanki 1348821

Supervised by : Jeanette Budgett

Abstract

From ancient times, our ancestors have peered in to dark abyss circling above them, wandering what lies on the tiny shimmering dots in the sky. The fourth rock from the sun has always beckoned. The planet in ancient times was covered in oceans of water, has almost completely lost this most vital of resources. Yet this planet offers the greatest possibility of sustaining human life outside our pale blue dot.

This research project focuses on the premise that inevitably a Martian colony will be established. Maybe not today or tomorrow, but one day. With growing interest from the non-profit sector and thousands of volunteers that want to establish a life on Mars that one day may not be far off. If this scheme is ultimately successful, what would the architecture of Mars be? In the present, and in 50 years after the first crew arrive?

Through analysing current proposals and literature studies this research project will attempt to push forth a hypothetical architectural solution to living and flourishing on the Red planet.

Acknowledgement

As this part of my life comes to an end, I would like to thank those who made it an unforgettable experience.

First and foremost I would like to thank my parents and two sisters. Your love and support has gotten me through my architectural studies.

Jeanette Budgett and Jaffer AA Khan, thank you for being patient and always available for a chat when I needed. Your help has brought me and this project to the stage it is at.

Luke Gehron my American friend. Thank you for all your help with Grasshopper and Rhino.

Finally, all my friends and extended family. Thank you for all your support over the last few years. Without you none of this would be possible.

0.0
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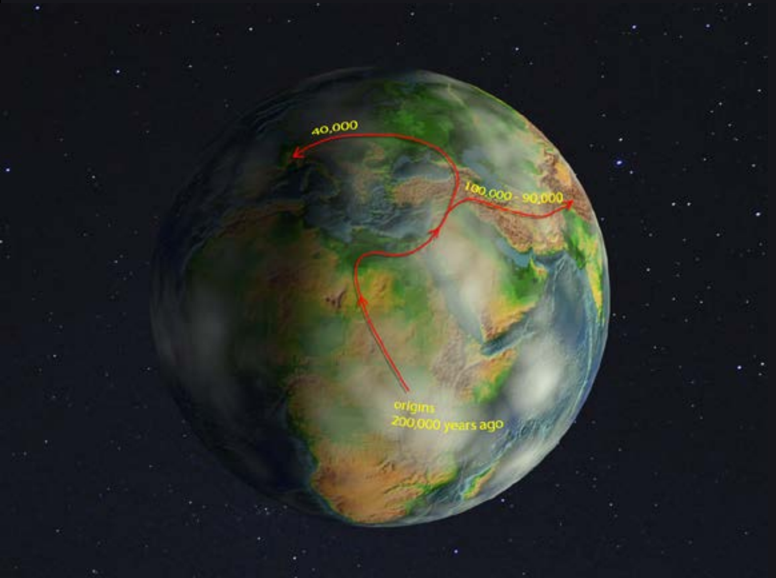
1.0 Introduction

The future of the past is in the future

The future of the present is in the past

The future of the future is in the present

— John McHale, 1965, in *Architectural Design* 2000+, February 1967, p 64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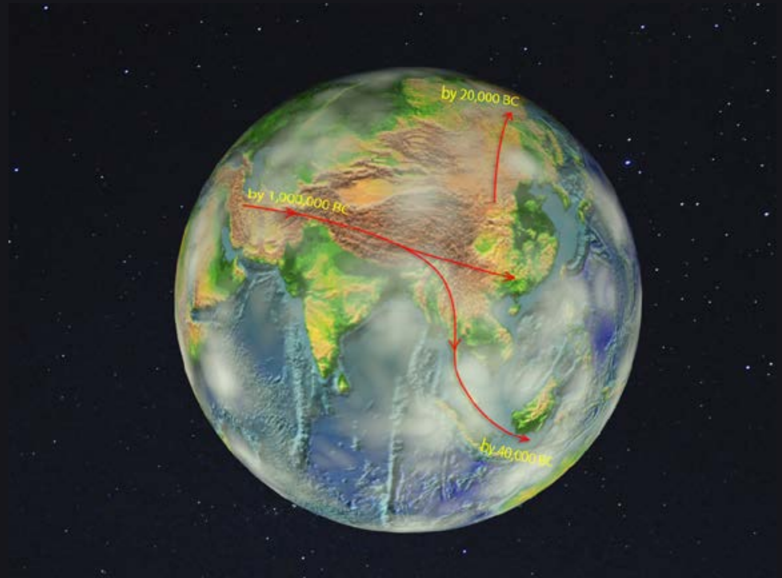
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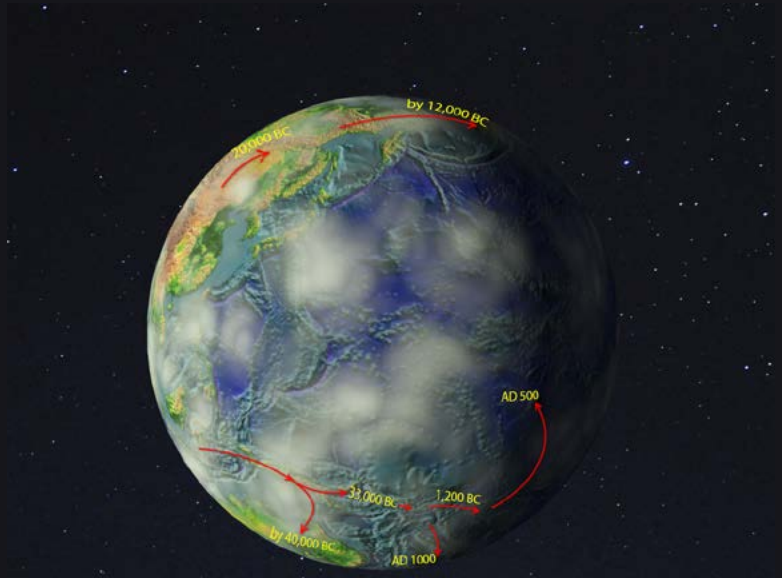
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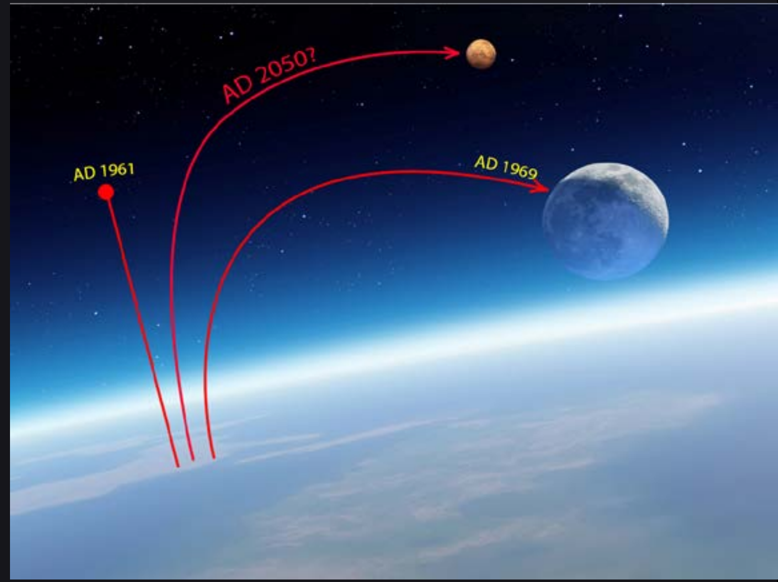

AD 2050?
AD 1961
AD 1969

Figure 4 - *Image page 11 - Deep Space*
Figure 5 - *Images previous page - Historical human migration and movement.*

1.1 Background of the Project

This project explores the possibility of creating an architectural intervention on a celestial body other than Earth. Architects have, as the vocation has developed over the centuries, pushed the boundaries and explored visions and needs of each age.

From primitive cave dwellings of ancient times to the tallest sky scrapers of the 21st century, architects have shaped their environment and context to provide for habitable spaces. As the human race has evolved, we have explored and conquered even the harshest environments on the planet. Similarly, architecture has morphed and evolved to provide for the needs of occupants.

Since 1957, the human race has also had a presence in the vastness of Space. 1969 brought the greatest human achievement. Neil Armstrong and Buzz Aldrin were the first two people to have walked on the surface of an extra-terrestrial body. After which various space flights and moon landings have occurred. Now there is a permanent human presence in space on the International Space Station (ISS).

Mars has consequently become the next destination for human exploration. It seems that a realistic mission to explore Mars is entirely possible within 50 years and by some accounts as early as 2037[1]; with some proponents arguing that a permanent human presence be established.[2]

"The real Mars is a world of wonders. Its future prospects are far more intriguing than our past apprehensions about it. In our time we have sifted the sands of Mars, we have established a presence there, we have fulfilled centuries of dreams!"[3] The Phoenix, Spirit, Opportunity and Curiosity rovers (among others) have created a vital link between Mars and Earth. The rovers over the years have provided invaluable information of the current state of the planet and given us a wealth of knowledge of the history of the planet. All of this information informs the technical aspect of this research project.

"For architects, designing for Space is now becoming less a matter of speculation and more one of live projects."[4] Every manned mission into the cosmos has been for the sole purpose of exploration and research. The next frontier in space exploration would be establishing a permanent human presence on Mars.

With the inevitability of Mars missions within the next two decades, architecture has a significant role to play in the eventual colonisation of the planet. Architecture will shape the spaces colonists will inhabit, the food they will eat, the air that they breathe, the integration of people from different backgrounds, and the effects of living in long term isolation with a small group of people. These are just few of the architectural issues that architects in this field will have to address. Another issue that will be of importance is that of construction on a foreign planet. Robotics and 3D printing have become a big part of modern architectural research, having huge implications for terrestrial construction. This technology could play a significant role in construction on Mars. This project will outline the possibility of creating and occupying spaces that humans will be able to survive and thrive in on the Red Planet.

1 PTI, "NASA aims to put man on Mars by 2037", last modified February 25,2007. http://articles.economictimes.indiatimes.com/2007-09-25/news/27683629_1_space-tourism-manned-mission-red-planet.

2 Neil Leach, "Buzz Aldrin : Mission to Mars." Edited by Neil Leach. *Architectural Design*, 2014, 43.

3 Carl Sagan, *Cosmos* (New York, NY: Random House, 1980), 69.

4 Helen Castle, "Editorial." Edited by Neil Leach. *Architectural Design*, 2014, 5.

2.0 Scenario

2.1 Research Question

What role does architectural design play in the creation of a permanent inhabitation on Mars?

2.2 Aims/Objectives

To explore architectural design through advancements in algorithmic master-planning, 3D Printing technology, robotics and parametric design.

2.3 Mars One Mission Architecture

Mars One is a non-profit organisation founded by Dutchman Bas Lansdorp, set up to send humans on a one way mission to Mars starting in the year 2027. The organisation has set up a road map of how they hope to colonize the Red Planet beginning in 2013 with a crew selection process. 200,000 people applied for this opportunity and through various selection criteria the process has now yielded 100 final applicants who will begin initial training. 24 full-time participants will be selected to take part in intensive training to conduct the greatest human expedition to date. Finally four participants will be given the ultimate opportunity to become the first colonist of Mars.

The most unique aspect of Mars One's plan is the prospect of sending people on a no-return policy to Mars. To achieve this Mars One's mission plan consists of series of precursor missions, to determine the capability and deployment of key technologies. Finally a 4 member crew on a one-way mission will leave Earth.

The mission will begin with the launch of a Mars surface lander in 2018. The lander's main goal for this mission is to exhibit key technology to sustain human life on the Red Planet. Two of the technologies that will be tested are the deployment of thin-solar array for electricity generation and an oven to extract water from the Martian regolith. At the same time a Mars orbiting satellite will be deployed to set up the communication system for both the precursor and later missions.[5]

Based on the success of the initial mission, a follow up mission is planned for launch in 2020. This mission will involve the deployment of a multi-purpose rover to a predetermined site. The rover will determine the most appropriate site for settlement and will prepare for the arrival of the habitation modules.

The next stage of the mission will involve the launch of six modified SpaceX Dragon[6] spacecrafts in 2022 and upon landing in 2023 will be assembled by previously arrived landers to form a continuous habitat. The six landers will come in three variants, each designed for a different function.

Specifically they are:

• Living Units: which each contain a 500 m3 inflatable structure, an airlock for crew, wet areas of the habitat, such as the waste and hygiene compartments.

5 Mars One, "Mars One: Roadmap" accessed April 15, 2015. http://www.mars-one.com/mission/roadmap.
6 Space Exploration Technologies Corp, "Dragon" accessed April 16, 2015. http://www.spacex.com/dragon.

• Life Support Units: air revitalisation, water processing and waste management technologies, stores, thin solar arrays for electricity generation.

• Cargo Units: extra storage and spare equipment for the habitat.[7]

For the purposes of redundancy, each habitat will have two copies of each unit. After the emplacement of the habitation units, thin solar arrays are deployed along with the in-situ resource utilization (ISRU) system. Rovers will deliver regolith to the ISRU oven which will extract the water. Some of the water through a process of electrolysis will be converted to breathable oxygen for the crew. At the same time an atmospheric processor will extract and store Nitrogen from the Martian atmosphere.

Before the crew leave Earth it is expected that the ISRU system will have produced 3000 litres of water, 120 kg of stored oxygen and enough oxygen and nitrogen to support a breathable atmosphere of 0.7 bar within the habitat.[8]

7 Do Sydney, Koki Ho, Samuel Schreiner, Andrew Owens, and Olivier de Weck. "An Independent Assessment of the Technical Feasibility of the Mars One Mission Plan". Paper presented at 65th International Astronautical Congress, Toronto, September 2014, http://dspace.mit.edu/handle/1721.1/90819.

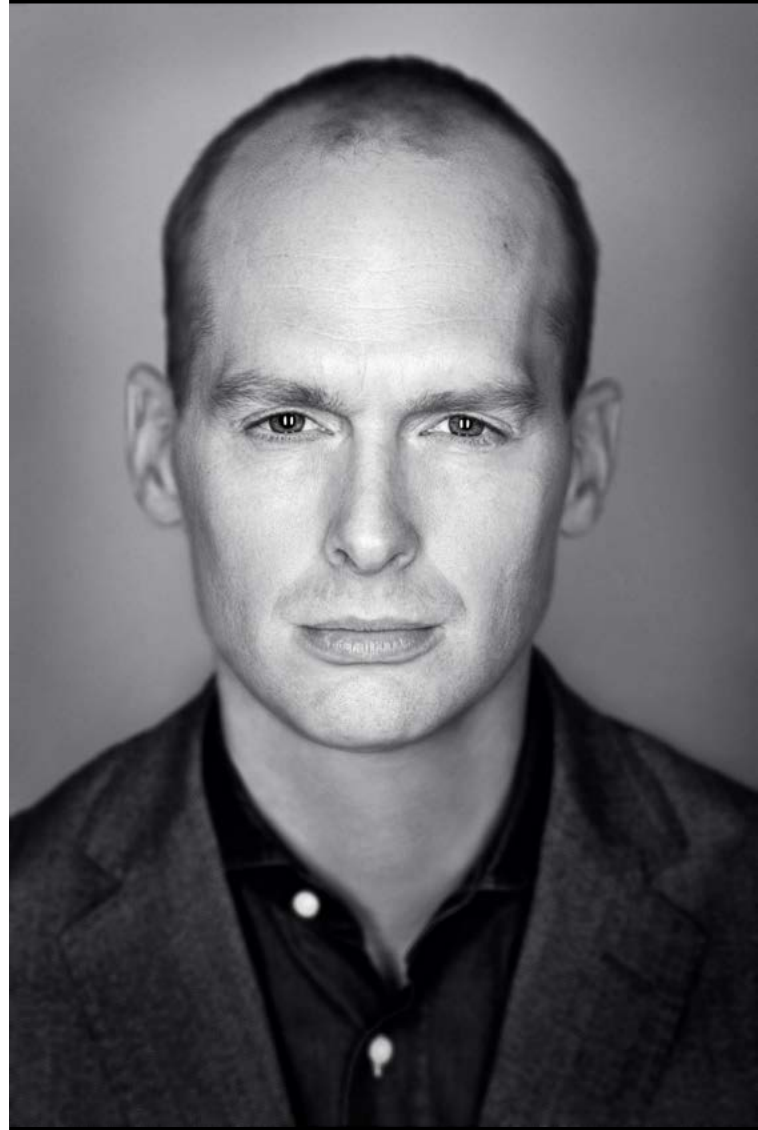
A separate human lander unit based on the Dragon module will bu used to deliver the crew to the surface in the year 2024. Another six habitation landers will be launched in the same launch window with equipment to support a second four person crew. Upon landing in 2025, the first crew will enter the habitat, activate the food growing system and integrate the second lot of six landers into the initial habitat.

The newly added units will support the next four person crew, who will leave in 2026 along with another six habitation units for the next four member crew.

This system of four member crew launches along with six landers will continue every two years, allowing the settlement to gradually grow over time.

8 Mars One, "Mars One: Roadmap" accessed April 15, 2015. http://www.mars-one.com/mission/roadmap.

Figure 6 - *Image right - Bas Landsorp, Founder and CEO of MarsOne.*



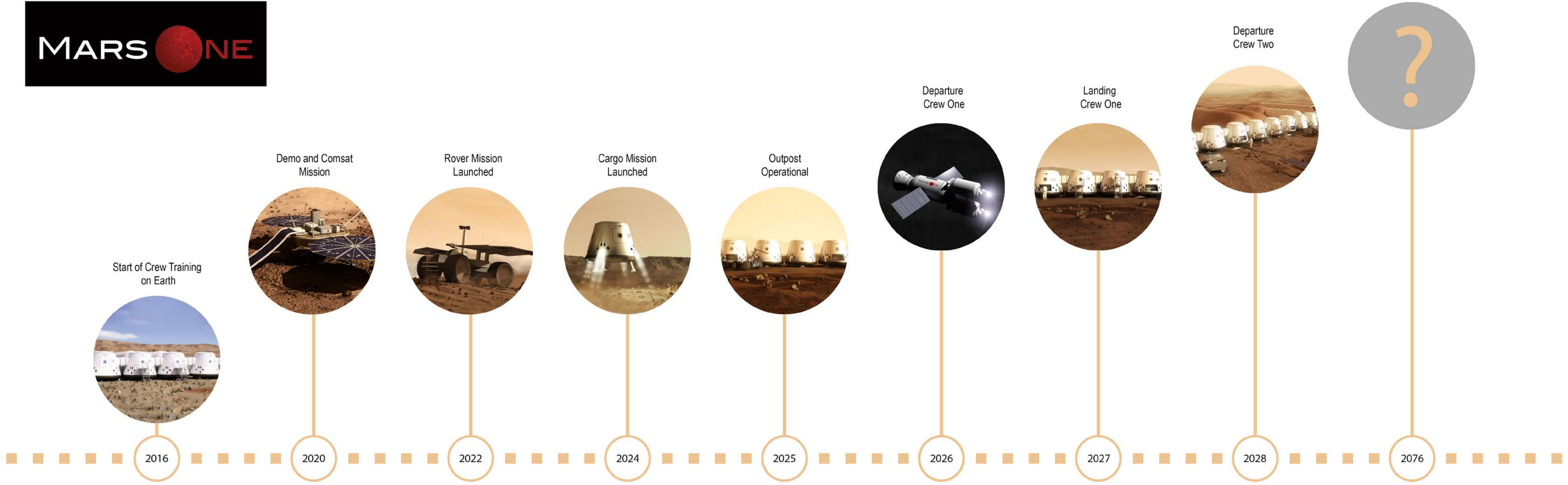

MARS ONE
Start of Crew Training on Earth
2016
Demo and Comsat Mission
2020
Rover Mission Launched
2022
Cargo Mission Launched
2024
Outpost Operational
2025
Departure Crew One
2026
Landing Crew One
2027
Departure Crew Two
2028
?
2076

Figure 7 - *Image previous page - Timeline of Mars One's mission architecture.*

Figure 8 - *Image right - Cut away diagram of MarsOne's proposed habitation modules.*
Figure 9 - *Image below - Plan of MarsOne's proposed habitation modules.*

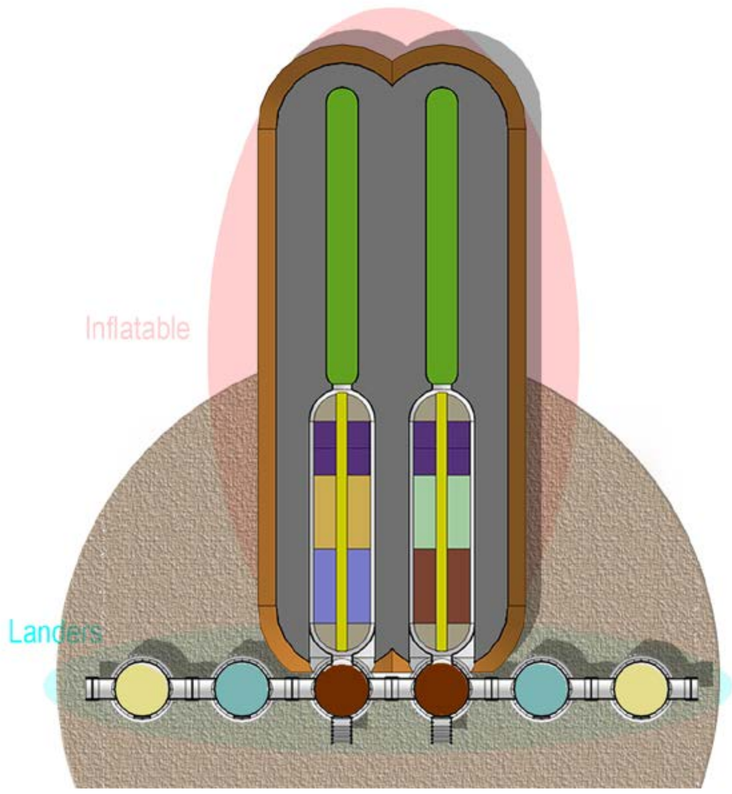
2.4 Habitation Design

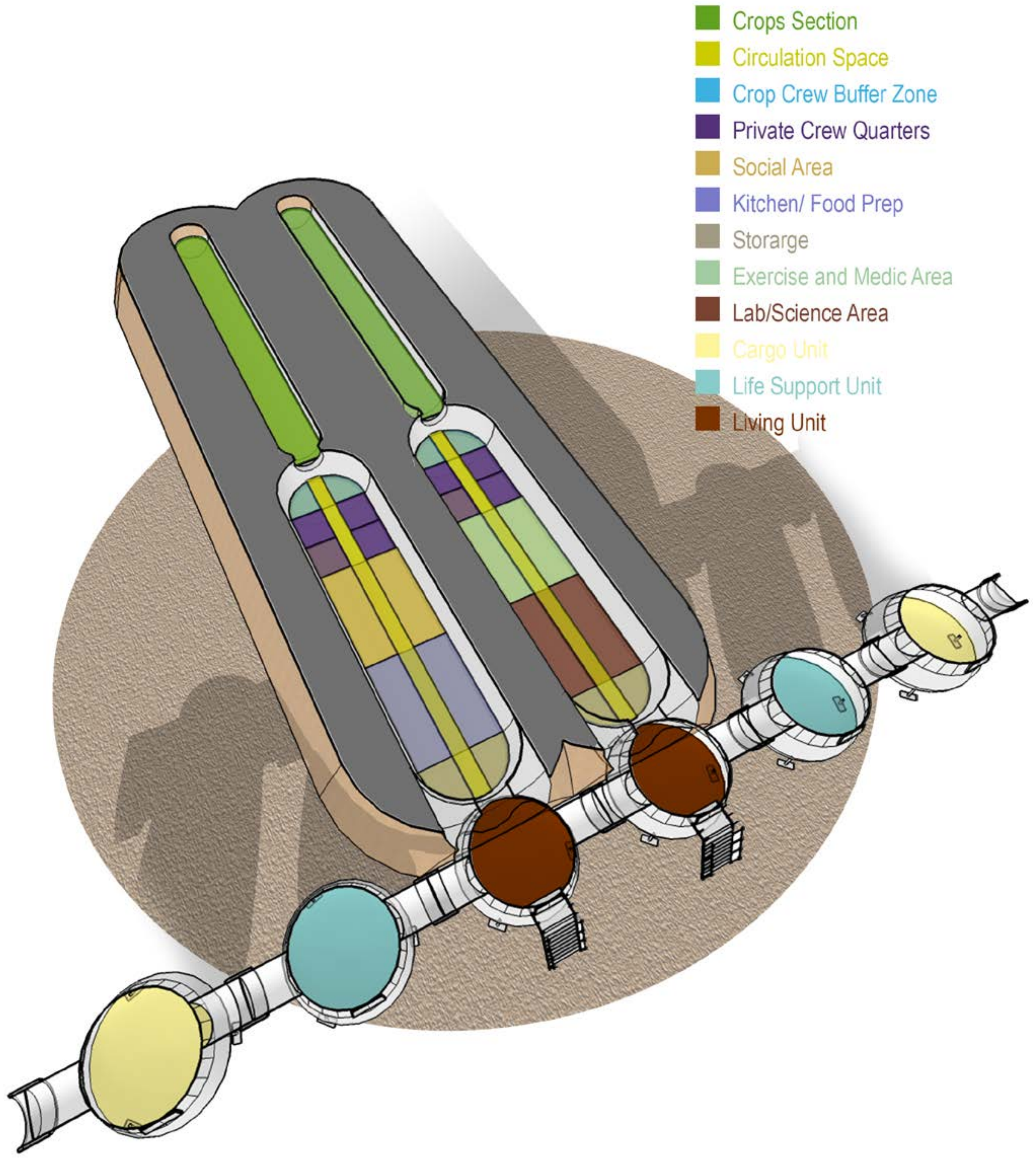
Mars One has designed a 200 square meter modular habitation system for the four member crew to live, work and play in. Each system is comprised of six small landers and two inflatable capsules. The landers will act as airlocks, storage space, and house all life support equipment while one of the inflatable units will act as main living and working space and the other as a crop production space. The interior spatial layout of the inflatables are continually being developed and at present the design is divided into:

- Kitchen and food prep
- Social area
- 4 x Private crew quarters
- 2 x 100 sqm crop growing areas
- Exercise and medical area
- Lab/Science area
- 6 x Landers

Mars One Model	Area (m^2)		Area (m^2)
Module 1		**Module 2**	
Main Section	75	Main Section	75
Crops Area	100	Crops Area	100
Total	**175**		**175**
Break Down			
Kitchen/Prep Area	30	Lab/Science Area	30
Social Area	30	Exercice and Medic Area	30
Crew Quarters	6	Crew Quarters	6
Crew Quarters	6	Crew Quarters	6
Crops Area	100	Crops Area	100
Total	**172**		**172**
Lander	10	Lander	10
Lander	10	Lander	10
Lander	10	Lander	10
Total	**202**		**202**
Per/Person	**50.5**		

Table 1 *Left - Breakdown of MarsOne areas from research.*





2.5 Growth of Colony

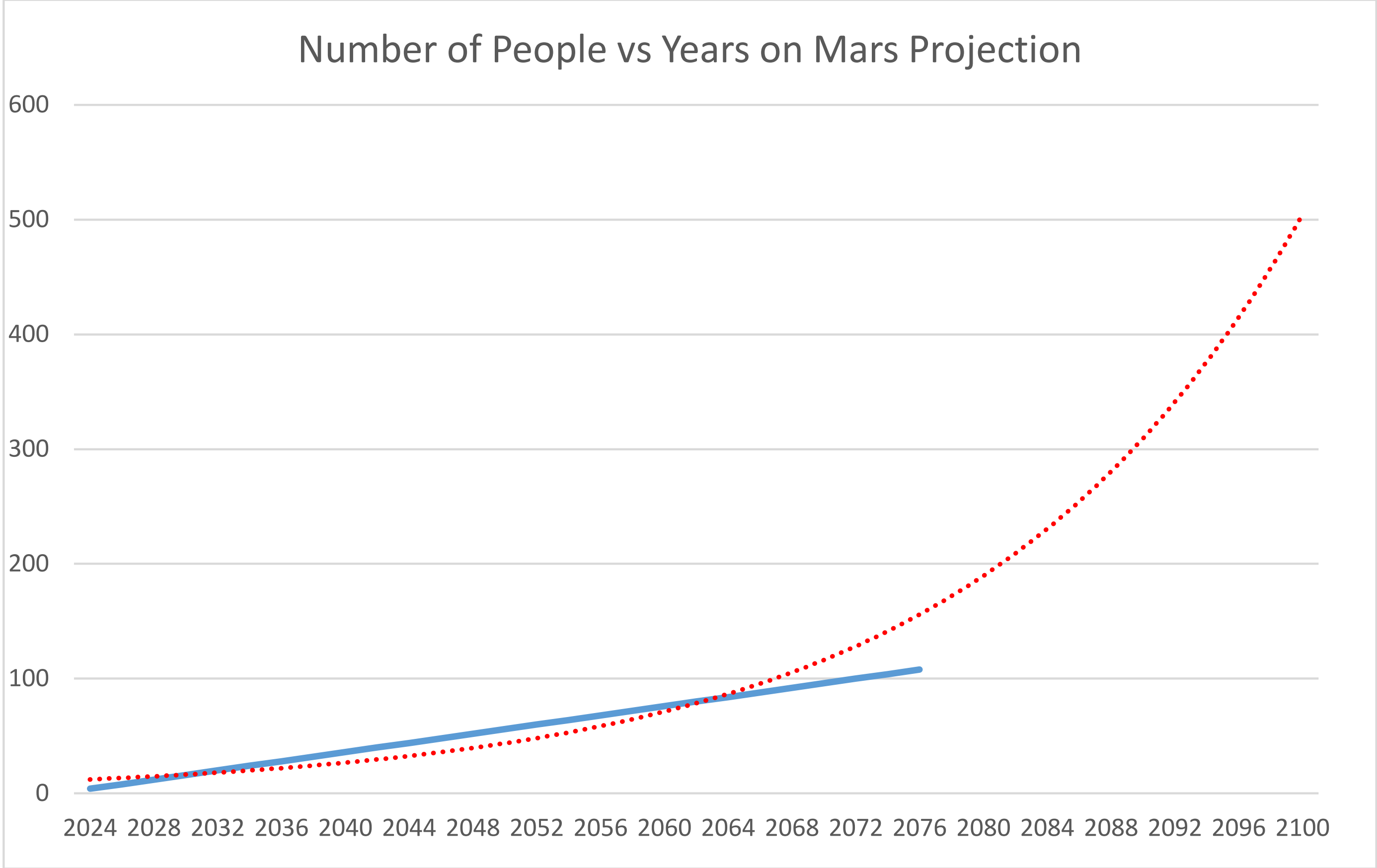


Figure 10 - Image next page - Sets of Beds Inclined Toward Mount Sharp.

Mars One plans to send 4 new crew members every 2 years to grow the colony. This would mean that within 50 years the colony could grow to over 100 people. This projected growth raises the question of whether the current architectural solution would be a sustainable way of housing the ever increasing number of people. This number could also exponentially increase if crew members have children. Mars One is not advising this in the immediate future, as there are many unknowns to how a fetus would grow in the reduced gravity environment of Mars.[9]

Architectural design has a big role to play in the eventual expansion of the colony. A permanent and ever growing colony would require substantially larger and ever changing functional and spatial requirements. The value of architectural design increases evermore in such a situation as it will provide for and create living environments that are more human friendly.

9 Mars One, "Can the Astronauts Have Children on Mars? - Health and Ethics - Mars One," accessed April 5, 2015. http://www.mars-one.com/faq/health-and-ethics/can-the-astronauts-have-children-on-mars.

3.0 The Brief

3.1 The Voyage There

A voyage to Mars would take about 180 days.[10] Astronauts visiting the ISS are usually on 6 months rotation, partly designed to reflect the time it takes to get to Mars.[11]After a long space flight, astronauts often find it difficult to stand and orientate themselves, they suffer muscle atrophy, loss of bone density and in some cases blindness.[12] NASA is currently doing specific tests on the effects of living in a long term micro-gravity environment. Astronaut Scott Kelly and cosmonaut Mikhali Kornienko are spending an entire year aboard the space station. The mission is set up to answer the question "does spaceflight affect the human body all the way down to the genetic level? And if so, can a study of those changes help protect or even select future astronauts?"[13] With the ultimate goal of "prepare[ing] humans for the long journey to Mars."[14] Astronaut Scott Kelly's identical twin Mark, offers scientist the perfect comparison with the same tests being conducted on both subjects.

Mars has a gravitational pull 38% of that on Earth. Landing on the Martian surface, will be easier on the body than on Earth because of this. However, in the long term "the full force of gravity that our bodies have adapted to will not be present to re-strengthen the astronauts' cells, bones, and muscles as they readapt to a gravity environment. Adjusting to this lower level of gravitational pull on Mars may cause a physiological change in the astronauts' bone density, muscle strength, and circulation making it impossible to survive under Earth conditions if they were to ever return."[15] Therefore creating a permanent base is a more desirable alternative, as Mars One is proposing.

10 Robert Zubrin and Richard Wagner, *The Case for Mars: The Plan to Settle the Red Planet and why we Must.* Rev ed. (New York: Free Press, 2011). 91.

11 Nikita Marwaha, "How Will Living on Mars Affect our Human Body?," accessed July 29, 2015. http://www.spacesafetymagazine.com/space-exploration/mars-mission/earthlings-martians-living-red-planet-affect-human-bodies/.

12 Calla Cofield, "Space Twins: Genetic Science Meets Space Travel on One-Year Mission," accessed July 29 2015. http://news.yahoo.com/space-twins-genetic-science-meets-space-travel-one-122605088.html

13 Ibid

14 Ibid

15 Nikita Marwaha, "How Will Living on Mars Affect our Human Body?," accessed July 29, 2015. http://www.spacesafetymagazine.com/space-exploration/mars-mission/earthlings-martians-living-red-planet-affect-human-bodies/

3.2 Architectural Issues

Mars One's proposal has significant shortcomings architecturally. The proposed habitations are extremely functionally driven in programme and layout of the design. The current habitation design is based solely on the creation of the bare minimum a human being would require to live in on a foreign planet. The proposal is driven more by necessity than design. A future Martian architecture could be able to move away from a strictly functional design approach and take on board the dreams of creating truly holistic communities on Mars.

Further architectural issues Mars One's proposal fails to address is that the design only allows linear growth. As the colony will grow more landers will land and the repetitive process of attaching a new series of six landers to the existing six will result in growth only in one direction. This in turn results in circulation becoming extremely difficult and linear. As per the design of the modules, circulation between each new habitation system will happen through the landers or by going out into the Martian atmosphere. There is also no privacy during circulation as there is no secondary circulation. Overlapping of functions and programmes will occur as the settlement grows. Each modular system will introduce the same spatial qualities as the existing ones. This will cause significant redundancies in functions.

Another significant shortcoming is there is no visual connection to the landscape. Inflatable habitats will be buried under Martian regolith to protect the crew from solar radiation.[16] This will mean that there will be no view of the Martian landscape. No sense of communal living as all the social spaces are isolated in each individual module. As the colony grows and more people arrive, more social interaction between individuals would be beneficial in creating a more complete living and working environment.

50 square meters of living space per crew member is extremely contained. The inflatable design only offers a 2.3 meter high ceiling space

16 Mars One, "Mars One: Roadmap" accessed April 15, 2015. http://www.mars-one.com/mission/roadmap.

Figure 11 - *Image previous page - Artist Impression of an extraterrestrial human habitat.*

with a maximum 4 meter width throughout the habitation. This may have significant psychological issues for crew members who have to live and work in constant contact with each other. Food growing/ green areas are completely separated from the living and working areas. Living in such a confined space would mean the physical environment of the living habitat will become extremely monotonous. The use of green plant material as a relief barrier and tool for breaking up the monotony of the interior maybe a successful tool.

Paul Zucker is one commentator who writes about addressing architectural issues that go beyond the basic functional requirements of built space. He writes, "Now, what is left to the modern architect is so that he many make buildings real works of art, beyond the fulfilment of all functional, economic, hygienic and sociological demands? Surely not the way of another repetition of traditional imitative forms!"[17] The Mars One proposal may serve as an intermediary solution as the first colonist arrive but not as a long term permanent solution. A more architecturally focused approach must be undertaken to address the issues highlighted. Mars One's proposal merely fulfils the requirements of surviving in an extremely inhospitable location. Architectural design can play a vital role in the creation of habitats that fulfil a more humanistic approach to living.

17 Paul Zucker. "The Humanistic Approach to Modern Architecture," *The Journal of Aesthetics and Art Criticism*, Vol. 2 (1940): 23.

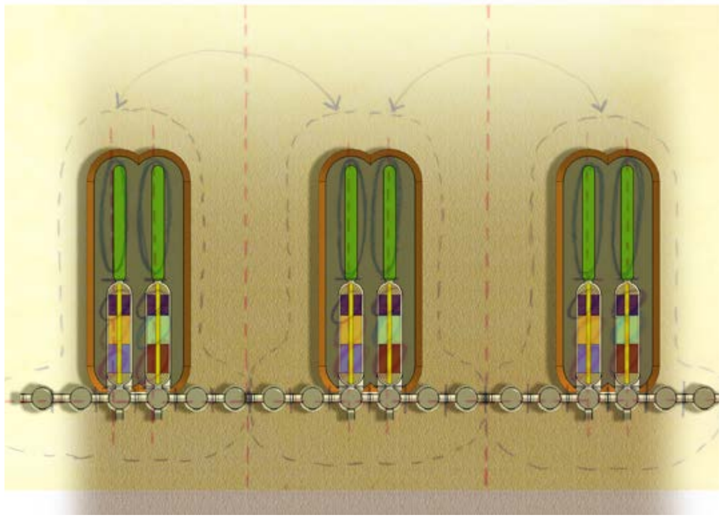


Figure 12 - *Image above - Graphic of linear growth suggested by MarsOne's proposal*

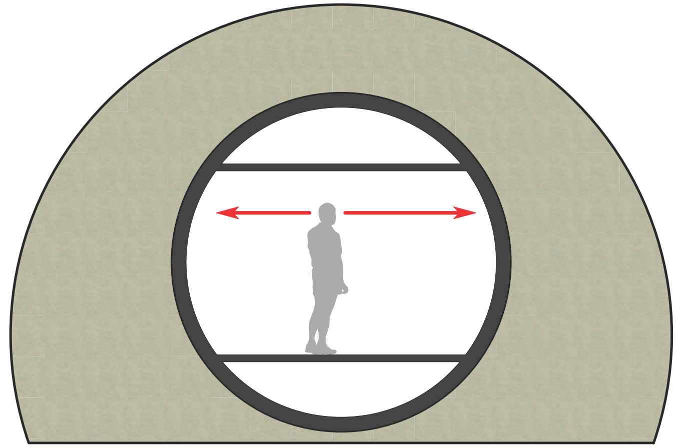


Figure 13 - *Image above - Graphic of lack of visual connection of crew.*

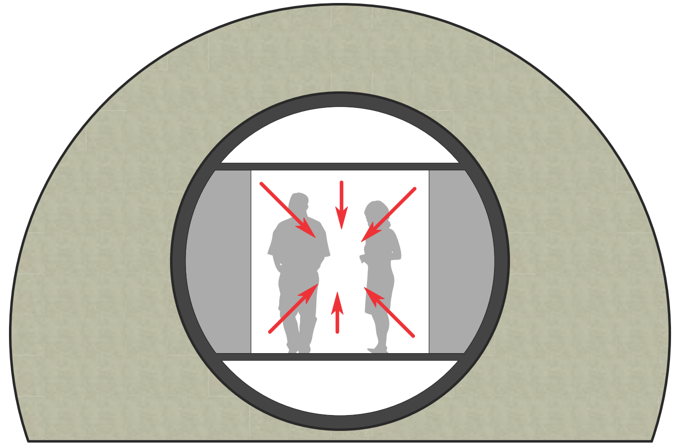


Figure 14 - *Image above - Graphic of confined living arrangment.*

3.3 Architectural Considerations

This research project will aim to develop a system of organic growth, which encourages the eventual expansion of the colony as a receptive organism. Architecturally, habitation on Mars or any other planet for that matter, will be more living organism than a building. As the need arises the growth and development of the new intervention should employ an organic and lucid model reflecting the complexity that is required to maintain the human condition. Furthermore, increased visual connectivity to the Martian landscape will be an essential architectural consideration. The alien landscape of Mars is beautiful and could be used as an architectural tool. Views to the landscape would give the inhabitants visual relief as opposed to the completely enclosed environment that is proposed by Mars One.

Paul Zucker comments on the risk of overemphasis and over simplifying the technical agenda. He writes, "The basis for his creation on an architecture, metatechnical beyond mechanisation, manifold and individualistic beyond standardisation, is one specific phenomenon. It is a phenomenon of general validity, universal and common to all of us: the entirely new conception of space, totally different from the two-dimensional feeling of the 19th century."[18] Creating a three–dimensional permeable configuration allowing the inhabitants to encourage communal living as opposed to the current "caged in" solution. Living in an isolated and contained environment long-term may have significant physiological effects on the inhabitants. Creating an architecturally varied and layered setting will help in the creating a more user-friendly environment.

Inhabitants will live, eat and depend on each other to survive in the hostile Martian environment. However, it is also very important to maintain privacy and a sense of belonging to ensure reduction in conflict. An integrated mixed-use planning technique must be adopted to ensure the effective use of resources to maintain and serve the inhabitants.

Scott Howe and Brent Sherwood in their book *Out of This World: The New Field of Space Architecture* suggest that "the psychological aspects of habitat design are affected by mission duration and crew size, among other considerations: the longer the mission, the greater the need for crew privacy and recreation. Increasing crew size increases the need for provisions for solitude, increases the complexity of human interactions, and adds social structure."[19] Further research into the effects of living in isolation and in confined places could provide a wealth of information on the design strategies to be included in this research project.

BioSphere 2 is one such experiment. The experiment was "a study designed to test survivability and to see whether a small group of humans could develop and live in a self-sustaining colony, as one might imagine on some distant planet in outer space."[20] One of the participants of the experiment Jane Poynter writes in her memoir, *The Human Experiment – Two Years and Twenty Minutes Inside Biosphere 2,* "As for me, I was sure it would never end. The psychological pressures of being locked up, enclosed with only seven other people and few distractions, built to a boiling point. The psychological baggage that we all carry around with us but normally have the energy to suppress began to float to the surface"[21] Mars One's crew will have to face similar problems and will have the added pressure of living in habitats much smaller and with no natural daylight, no normal day-night cycle, in a completely artificially lit and simulated environment.

Pyonter goes on to write "also, it is very common for crews in isolation to break into two factions, as we had. It happens in the Antarctic, in space and just about anywhere small groups are shut off from the rest of the world. In the Biosphere, we were living out some preordained group madness."[22] However, there have been successful missions. The Mars500 was a psychosocial isolation experiment conducted between 2007 and 2011, by Russia the ESA and China. The programme was a successful example of long term isolation being successful and which didn't end up braking into factions.[23] A notable issue the experiment revealed was that the Martian day cycle of 24 hours and 36 minutes may cause people to get out of sink and cause problems with sleep patterns, performance psychological health and physical health.[24]

Furthermore, Robert Zubrin and Richard Wagner in their book *The Case for Mars – The Plan to Settle the Red Planet and Why We Must* argues that "if you abstract yourself from America's contemporary comforts and look at human history, everywhere you will see people chosen essentially at random – whether as front line soldiers, refugees in hiding, prisoners, submariners, explores, trappers, or pre-twentieth-century merchant seamen-all of whom had to and by and large did competently endure long-term conditions of isolation, privation, and psychological stress greatly exceeding what the select crew of a piloted Mars mission will face. Humans are tough. We have to be. We're the survivors of the saber-tooth tigers and the glaciers, of tyrannical

18 Paul Zucker. "The Humanistic Approach to Modern Architecture," *The Journal of Aesthetics and Art Criticism*, Vol. 2 (1940): 24.

19 Scott A Howe, and Brent Sherwoord, *Out of This World : The New Field of Space Architecture*. (Reston, VA, USA: American Institute of Aeronautics and Astronautics, 2009). ProQuest ebrary. Web. 24 September 2015.

20 Kara Rogers, "Two Years Under the Glass: The First Biosphere 2 Mission," accessed July 30, 2015. http://blogs.britannica.com/2011/09/years-glass-biosphere-2-mission/

21 Jane Poynter, *The Human Experiment Two Years and Twenty Minutes Inside Biosphere 2* (New York: Basic Books, 2009). 234

22 Ibid

23 DNews, "Jealousy a Problem During 'Mars Mission'," accessed July 28 2015. http://news.discovery.com/space/mars-500-mission-jealousy-111106.html

24 Ian Sample, "Fake mission to Mars leave astronauts spaced out," accessed July 28, 2015. http://www.theguardian.com/science/2013/jan/07/fake-mission-mars-astronauts-spaced-out

empires and barbarian invasions, of horrible famines and devastating plagues. You name it, you've got ancestors who have faced it, and overcame it. The same can certainly be said of the hand-picked and highly trained crews of the first human missions to Mars.

The human psyche will not be the weak link in the chain on piloted mission to Mars. On the contrary, it is likely to be the strongest."[25]

In any case, there is an opportunity for architecture to play a pivotal role in providing an environment that is safe both physiologically and psychologically. This research project is set in a time where 100 initial colonist have already established a presence on the planet. Research indicates that a larger number of people would prove to be less dysfunctional, have less conflicts and demonstrate less deviance.[26] Furthermore, Christopher Alexander's, *A Pattern Language* as a guideline in design strategies to form a more coherent and architectural approach will be adopted.

25 Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Red Planet and why we Must*. 141.
26 Marilyn Dudley-Rowley, Stewart Whitney, Sheryl Bishop, Barrett Caldwell and Patrick D. Nolan, "Crew Size, Composition, and Time: Implications for Habitat and Workplace Design in Extreme Environments," accessed July 30, 2015, http://spacecraft.ssl.umd.edu/design_lib/ICES01-2139.crew_design.pdf.

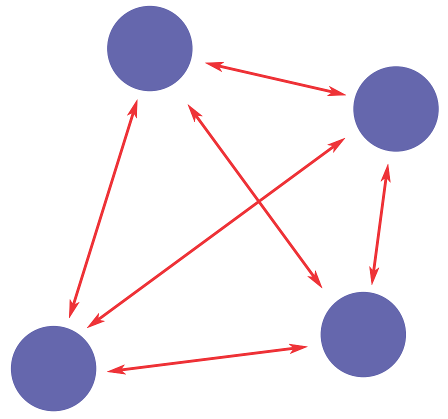


Figure 15 - *Image above - Graphic of organic growth.*

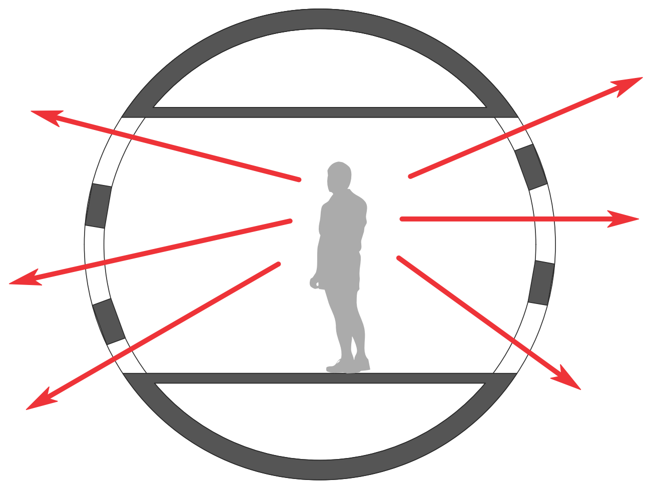


Figure 16 - *Image above - Graphic of visual connection.*

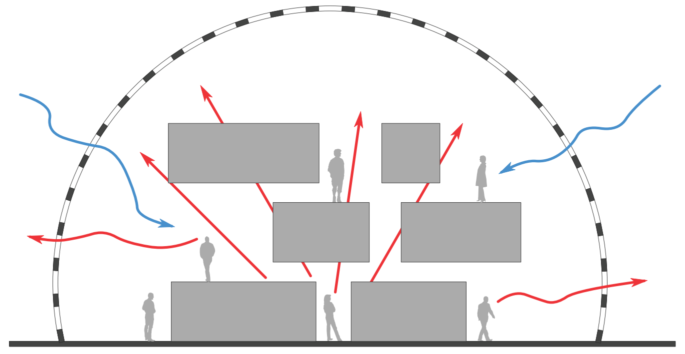


Figure 17 - *Image above - Graphic of permeable configurations.*

Figure 18 - *Image right page - Graphic of functions.*

3.4 The Program

This project will explore an amalgamation of functions and an appropriate shift in scale for a community of 100 people on Mars. The program will specially consist of:

- Medical Facilities
- Educational Facilities
- Food Storage Facilities
- Food Growing Areas
- Communal Spaces
- Private Living Spaces
- Workshop Facilities
- Laboratory Facilities
- Virtual Environment Spaces
- Exercise and Gym Facilities

4.0 Precedents

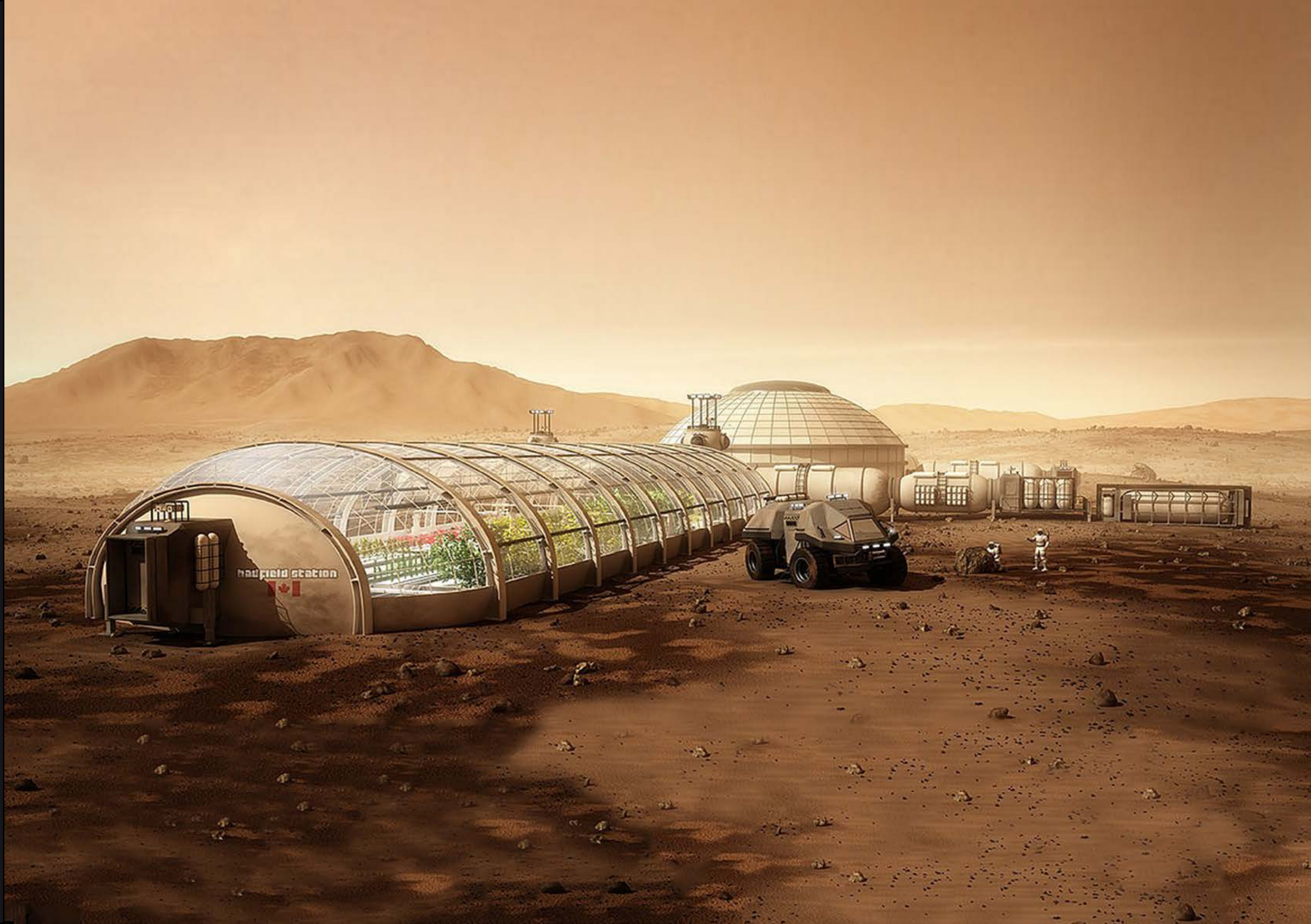


Figure 19 - *Image previous page - Artists impression of a Mars Base.*

4.1 Space Architecture

4.1.1 Fosters + Partners - Moon Base

Proposed in early 2013, the Foster + Partners Moon Base is a theoretical prototype developed for the European Space Agency (ESA). The design combines an inflatable architecture with 3D printing to create a habitable space for astronauts on the Lunar Surface.

The biggest benefit this solution provides for is the solution to logistics of lunar construction. Both NASA and ESA pursue a policy of in-situ resource utilisation (ISRU)[27] to ensure maximum use of materials available on site.

A mobile 3D printer would print over a nitrogen filled membrane structure. The 3D printer uses "a mobile printing array of nozzles on a six meter frame [using] a binding solution on a powder-like building material [lunar regolith] – built up layer"[28] to produce a solid, protective shell. The proposed base is on the South Pole of the Moon. Where the radiation of the sun comes in at angle and will require "1500 mm of regolith cover in the dominate direction of rays."[29]

Printing of lunar regolith requires the shipping of a binder solution to act as an adhesive to create a dense and compact structure. Depending on the volume of binder required this increases the cost of transportation. To mitigate this problem the designers have proposed to use "closed foam cells…as an initial compromise between strength, minimisation of binder and printability."[30] The cells are then filled with loose unprinted regolith to provide extra protection.

Inside the protective 3D printed layer and inflatable shell, astronauts are shielded from solar radiation, extreme temperature variations, and meteoroids. Furthermore, the interior is pressurised and atmosphere controlled, allowing the astronauts to walk around and work without wearing a space suit.

27 Neil Leach, "3D Printing In Space." Edited by Neil Leach. *Architectural Design,* 2014, 110.

28 Design Boom, "foster + partners to 3d print structures on the moon" accessed August,2 2015 http://www.designboom.com/architecture/foster-partners-to-3d-print-structures-on-the-moon/?utm_campaign=Sunday&utm_medium=email&utm_source=subscribers.

29 G. Cesaretti, "3D Printed Building Blocks Using Lunar Soil", *Alta S.P.A*, Executive Summary, May 2012, 11.

30 Ibid

Figure 20 *Sectional rendering of Foster+Partners Moon Base.*

Figure 21 *Image next page - Plan of interconnecting habitats proposed by Foster+Partners.*

This projects use of 3D printing and inflatable structures, will provide a wealth of knowledge on the construction methodology and use of in-situ resources that may be implemented on the Martian surface as opposed to the lunar surface.

Potential Advantages

By using this technology – the project addresses two of the most challenging aspects of this kind of endeavour; construction and transport.

• Autonomous construction – On the surface of Moon construction conducted by humans would be extremely difficult and dangerous. Difficulty would arise from lack of mobility that even the most modern suits provide and the constant danger of micro-meteoroids that may tear such suits.

• Transport – Using as much material that is available on the surface of the Moon, the designers have limited the amount of material required to be transported from Earth. This process allows construction to be cost effective, as "the cost of transporting raw materials into Space is prohibitive – potentially US$ 2 million for a single brick to be shipped to the Moon."[31]

• Reduced gravity means buckling forces are reduced.

• No wind and rain to contend with.

• No seismic activity.

31 Neil Leach. "3D Printing In Space." Edited by Neil Leach. *Architectural Design*, 2014, 110.

Potential Problems

• Large temperature variation on the surface of the moon may cause problems in curing and other construction processes.

• Length of a lunar day – which is 14 times longer than a terrestrial day – means that there will be long periods of time when there is no sunlight, resulting in no solar power if that is to be used as the primary source of energy.

• Problems associated with working in a vacuum and low light intensity.

• No concrete evidence of water existing on the surface of the moon.

• Robotic system needs to be fail proof.

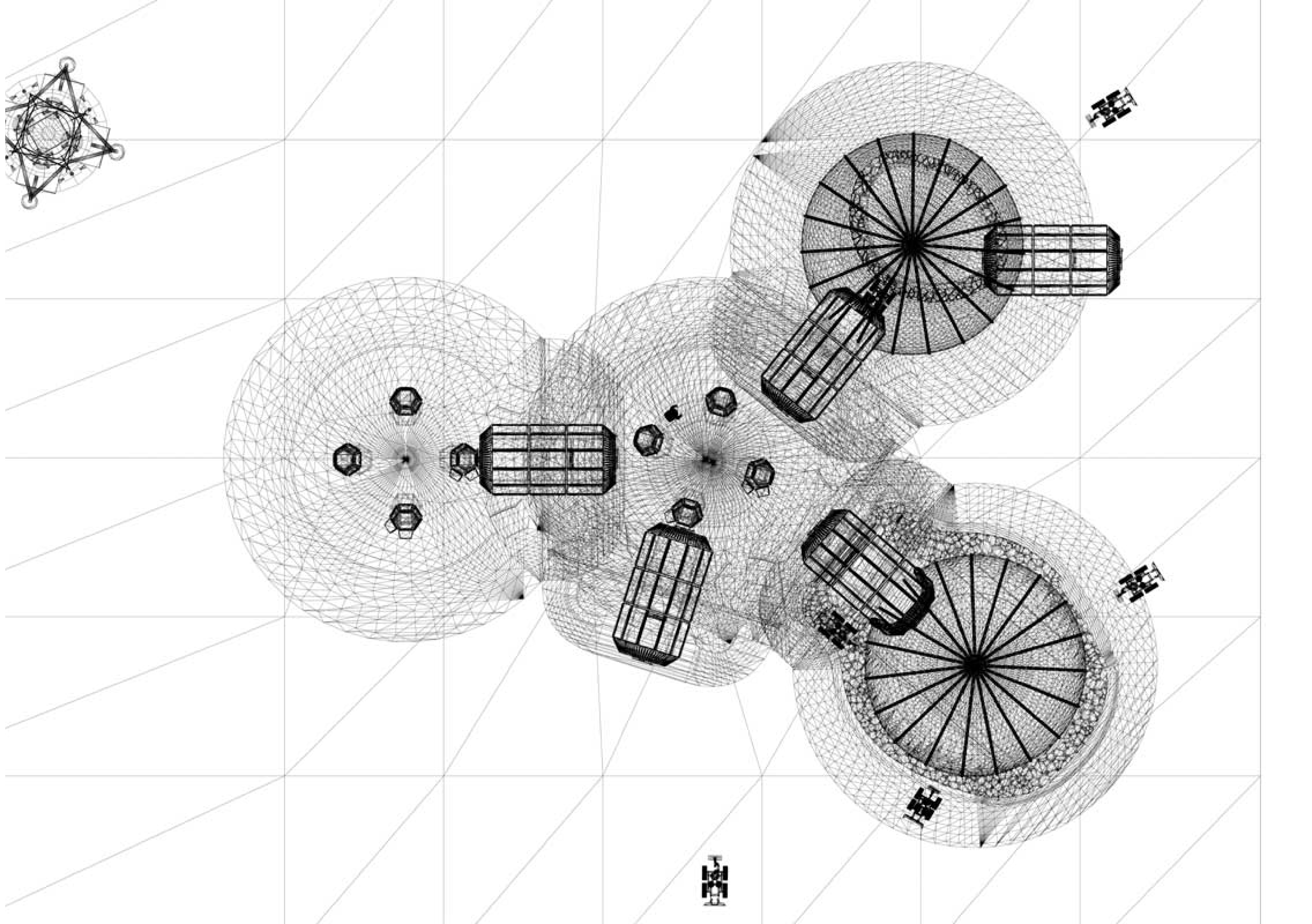


Figure 22 *Image next page - Sectional rendering of ZA Architects proposal.*

4.1.2 ZA Architects – Mars Colonisation

ZA Architects have developed a conceptual strategy to build permanent settlements on Mars, by using robotics and local materials.

The project would send robotic drilling machines to identify basaltic columns that were discovered on Mars in crater walls near Marte Vallis by NASA's Mars Reconnaissance orbiter. "Once they found an area of such buried columns, the robots would test them for strength and then remove the weakest ones as an entry point. They'd dig down like ants and open up a subterranean space, leaving some columns behind as support."[32]

The robots' excavations are sealed off in order to protect the interior from wind and dust. The entire construction process is done autonomously and astronauts only leave Earth once the initial underground structure is ready. The volume of the interior space is configured using a spider-web like weave created from basalt to create a multi-level.

Human friendly environments such as residential units and public meeting areas are constructed as modular units and are transported from Earth along with astronauts. Astronauts would complete construction by undertaking the more technical aspects of the project such as installing water making equipment, oxygen making equipment, and basalt processing line.

Subterranean construction provides for advantages and disadvantages which will be discussed next.

32 David Szondy, "ZA Architects design buildings for Mars", last modified September 11, 2013. http://www.gizmag.com/martian-architecture/28999/.

Figure 23 *Image next page - Rendering of surface conditions of ZA Archtiects proposal.*

Potential Advantages

• Underground housing provides the most protection from solar radiation.

• A constant temperature is achieved by going below the surface of Mars, which will make a comfortable environment for astronauts.

• Protection from wind and dust events that may occur on the surface of Mars.

• Takes on-board the maximum use of in-situ resources.

• Transport of autonomous construction equipment ensures a cost effective building strategy and human safety.

• Possible to grow own food in the insulated environment of the cave.

Potential Disadvantages

• Long term periods of living underground may have psychological ramifications.

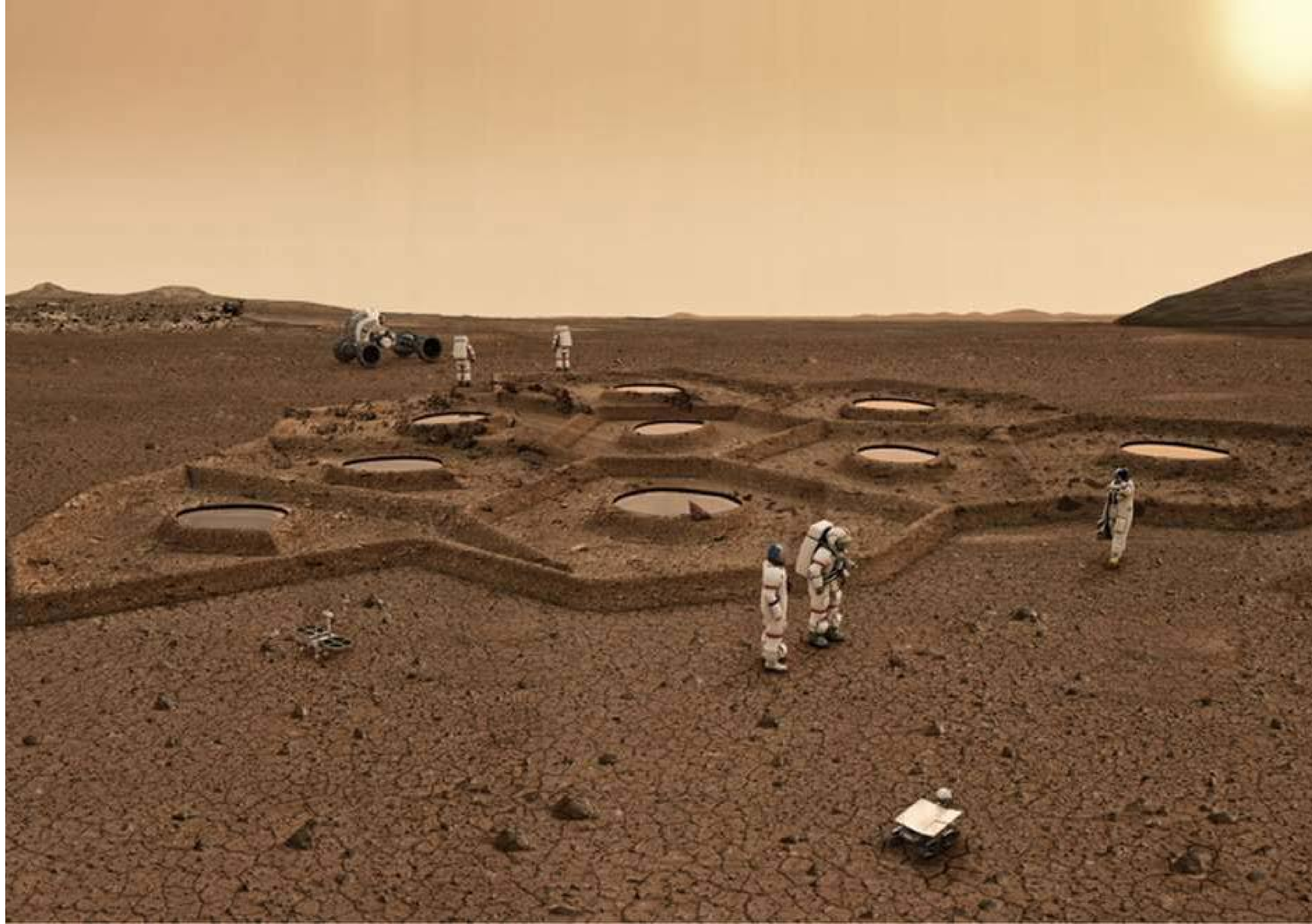
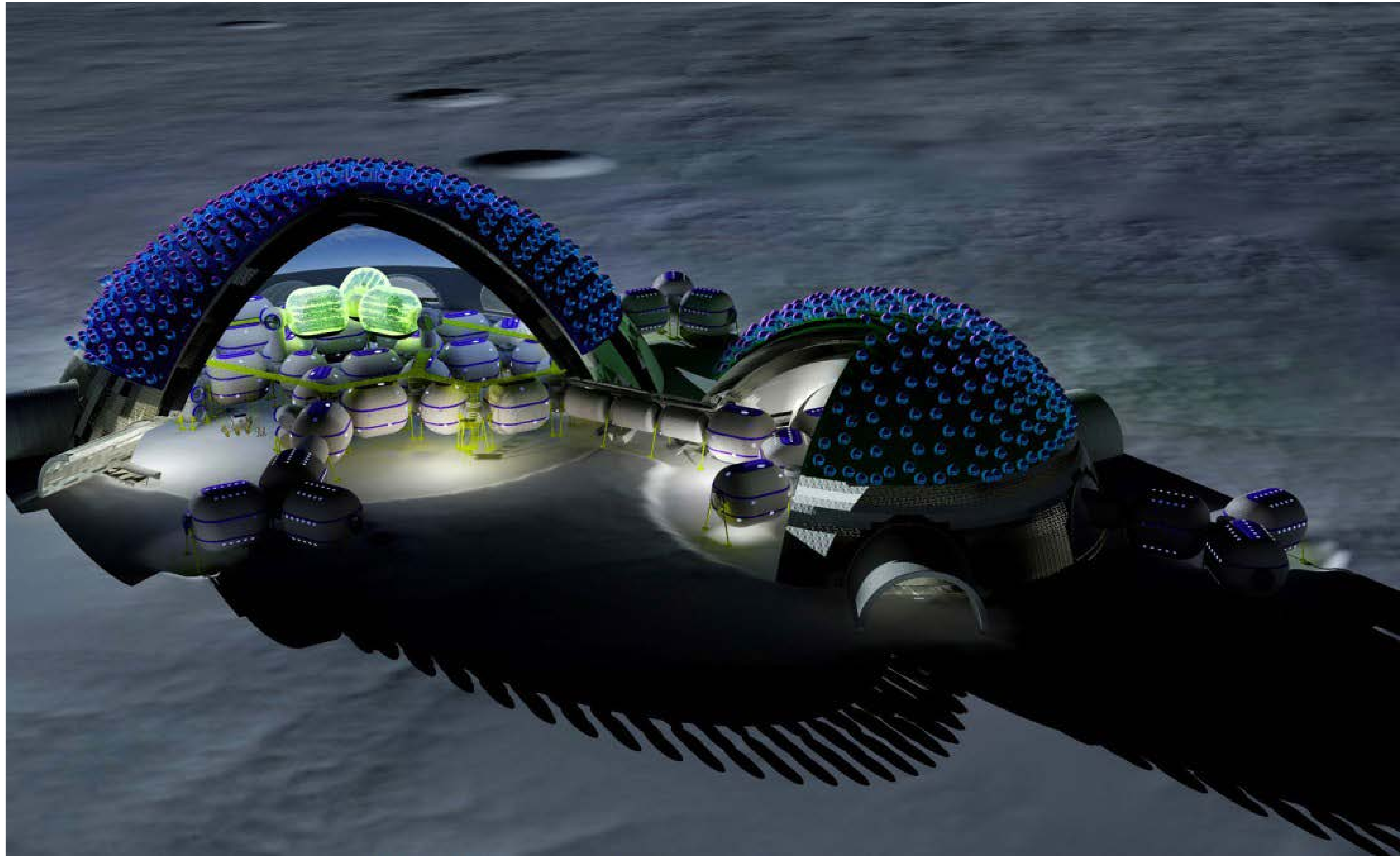


Figure 24 *Image next page - Cutaway rendering of MoonCapital proposal.*



4.1.3 MoonCapital – Andreas Vogler

Proposed in 2010, Andreas Voglers MoonCapital is a proposal for a lunar habitation located on the rim of the Shackleton Crater on the southern pole of the Moon. Vogler puts forward his vision of a feasible scenario of how 60 people can live on the moon by 2069. The design combines inflatable self-hardening concrete domes and swarming robot technology to create safe living environments for humans.[33]

The ultimate goal is to set up a large research station to house a deep-space telescope and take advantage of the virtually sterile atmosphere. It would contain areas for research, production, leisure, and a small hotel for visitors.[34]

MoonCapital explores the principle of organic growth based on a series of modules, with the initial phase consisting of two domes, the larger one for living and working the other smaller one for food cultivation and to house other mechanical equipment. This modular system allows growth and expansion as the new lunar colony evolves.

Smaller 11 meter diameter inflatable modules are deployed on six meter diameter rocket fairings which occupy the 135 meter diameter large dome. This system allows for a constant growth in the facility. Each module is than separated into three levels, which are connected to neighbouring modules through "rigid-carbon fibre nodes."[35] These nodes provide for a three way horizontal and two way vertical connection, the latter being achieved by staircases. Ceiling heights are kept between 2.4 meters and 2.6 meters and are lined with soft padding for protection in the low gravity environment.

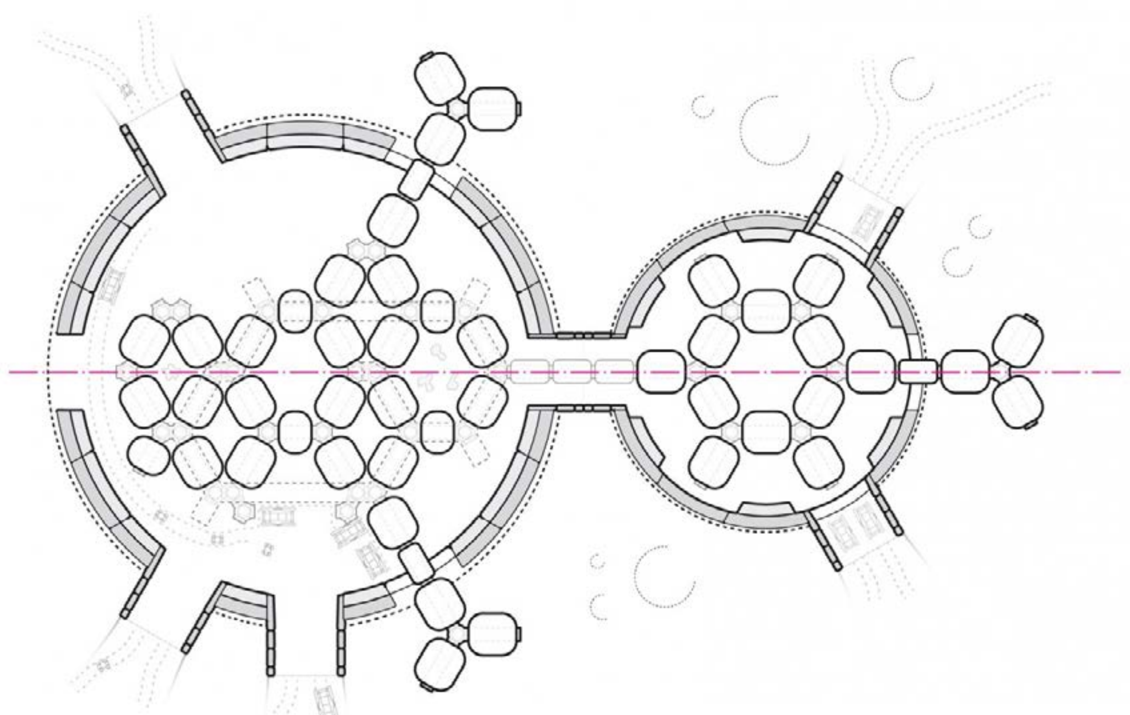
The project's most crucial aspect is the use of technology to mitigate the psychological and physiological effects of living in isolation and a low gravity environment. The interior of the large dome is designed to project a virtual representation of a terrestrial 24 hour solar cycle, because the Shackleton Crater experiences a 28 day lunar day/night cycle. The designers acknowledge that sensory

33 Andreas Vogler. "Moon Capital - Life on the Moon 100 Years after Apollo." Edited by Neil Leech. *Architecture and Design*, 2014, 32.

34 Ibid, 35.

35 Ibid, 35.

Figure 25 *Image right - Typical plan of modular layout.*



deprivation is a major concern[36] in an environment that is so confined and artificially controlled. To counter these issues, the design creates and respects private, semi-private, semi-public and public spaces allowing individuals maximum personal freedom. MoonCaptital also employs environmental control strategies, communication systems, audio systems and agriculture as stimulating countermeasures.

Physiological effects of living in low gravity are resolved by creating engaging spaces in the safety of the large radiation protected environment of the domes. These areas allow people to play spacesuit sports such as moon tennis, and moon soccer[37] and are also filled with sculptures "to fulfil inhabitants' desire for culture."[38]

Potential Advantages

• Cellular growth based on modular system to create a larger overall master plan is a good strategy and can be applied to the Martian context.

• Use of technology to create a rich environment for occupants will be a crucial tool to create a habitable environmental on Mars.

• Use of leisure activity as part of the facility to encourage communal living.

• Creating spaces for virtual environments may prove beneficial on Mars.

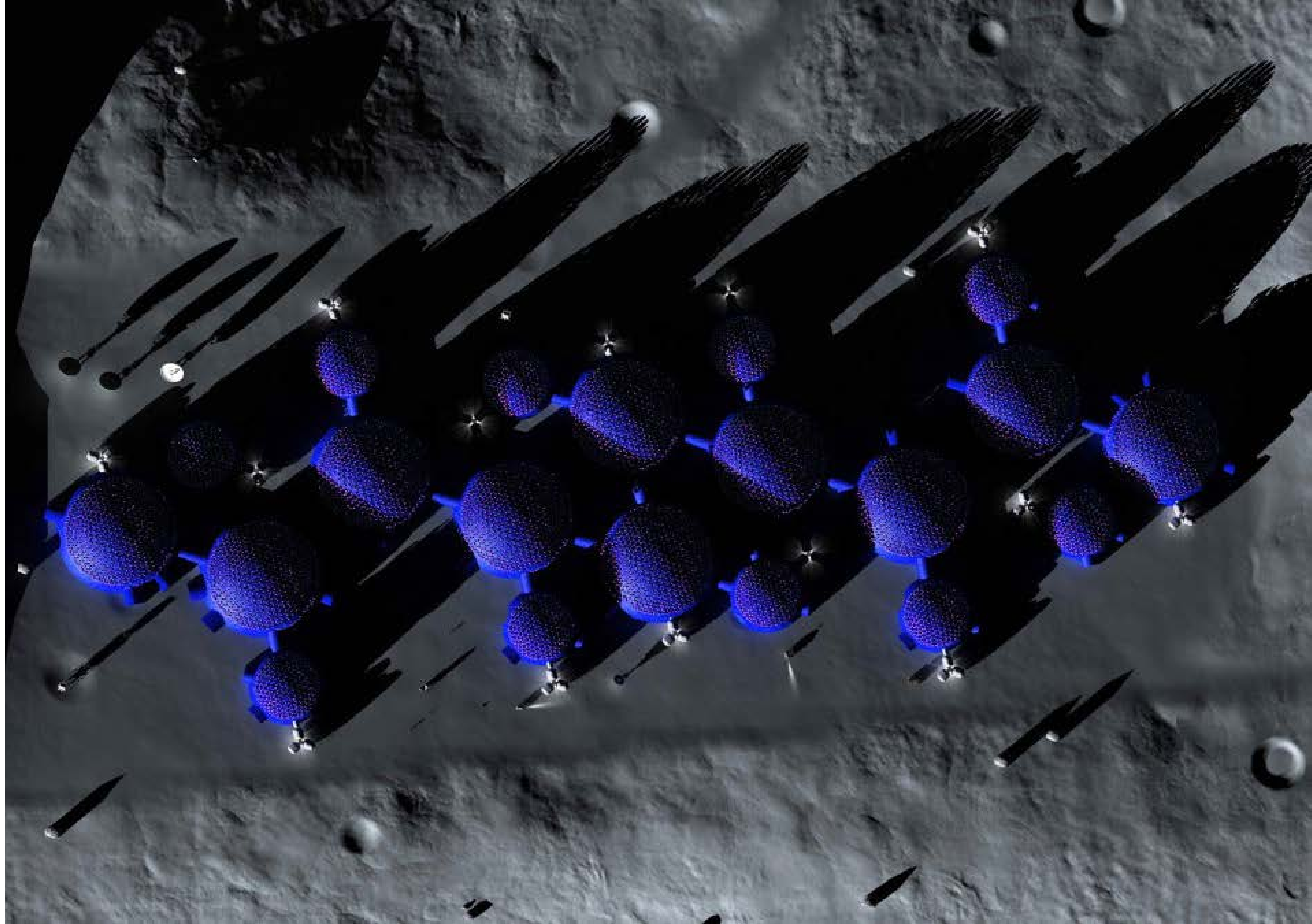
• Scale of the overall facility can be a basis for a design on Mars

Potential Disadvantages

• Internal volumes of the dome are treated as vacuum space and requires people to wear space suits in order to use.

• Unclear on whether virtual representation of environments are as fulfilling and engaging as the real thing.

Figure 26 *Image next page - Materplan of MoonCapital.*



36 Ibid, 35.
37 Ibid, 35.
38 Ibid, 35.

Figure 27 *Image next page - Photograph of typical dwelling in Matmata, Tunisa.*

4.2 Subterranean and Organic Architecture

4.2.1 Matmata – Tunisia

Etched into the edge of the southern mountains of Tunisia, are ancient habitats constructed by cave dwelling troglodytes. These houses are an example of ancient vernacular architecture carved out of the desert sandstone.

The houses form a network of underground links with neighbouring households in the community. Each individual house is centred on an open-air courtyard. These courtyards are essentially pits 10 meters deep and curvilinear in plan with a diameter of about 5 – 10 meters. The below ground courtyard forms an atrium that all connect to smaller rooms along the perimeter. These courtyards not only function as a circulation space, but as the centres of communal living and often become garden spaces as well.

They are often two-stories high with stairs carved out of the rock situated inside the open-air courtyard. Smaller 4-5 x 8 – 10 meters chambers with three meter high stud height are carved into the sandstone. These chambers act as bedrooms, kitchens, family rooms and other domestic activity spaces.

The interior spaces are often rendered white to reflect as much sunlight as possible and to brighten the space.

This example provides the greatest example of energy efficiency living. The natural sandstone provides a naturally insulating barrier between the harsh desert sun and the occupants during daylight hours. The same sandstone provides warmth during the night, when the desert temperature drops significantly. As a consequence the temperature of the homes remain a constant 20-22 °C year around.[39]

39 De Space Designs RSS, "Vernacular Architecture: Matmata, Tunisia," accessed August 27, 2015. http://despacedesigns.com/vernacular-architecture-matmata-tunisia/.

Figure 28 *Image next page - Plan of typical dwelling in Matmata, Tunisa.*

Potential Advantages

• Subterranean dwellings ensure temperature stability – beneficial in the Martian context as the huge temperature variation will require significant artificial heating and thus reducing the energy consumption.

• Provides for significant protection from extreme conditions of the Martian atmosphere such as winds, dust storms, frosts, cosmic and solar radiation.

• These subterranean structures were carved out using primitive tools and technology many centuries ago without much difficulty, this may suggest a similar approach might be feasible on Mars owing to the more sophisticated and technologically advanced tools available.

• Durable and long lasting – the example shows that constructing out of natural sandstone lasts for a long time and a similar approach may provide for an extremely long lived Martian solution.

Potential Disadvantages

• With Martian sunlight intensity at only 40% [40] percent of that of Earth, interior spaces will require artificial illumination.

• Long term living underground and limited sunlight may have an adverse effect on the occupant's physiological comfort. Added to the fact that the occupants will have limited interaction with the surface of the planet anyway, creating a visual barrier may prove problematic.

• An open-air depression will not work as the atmosphere of the interior spaces will need to be artificially controlled.

40 See chapter 5.1.4

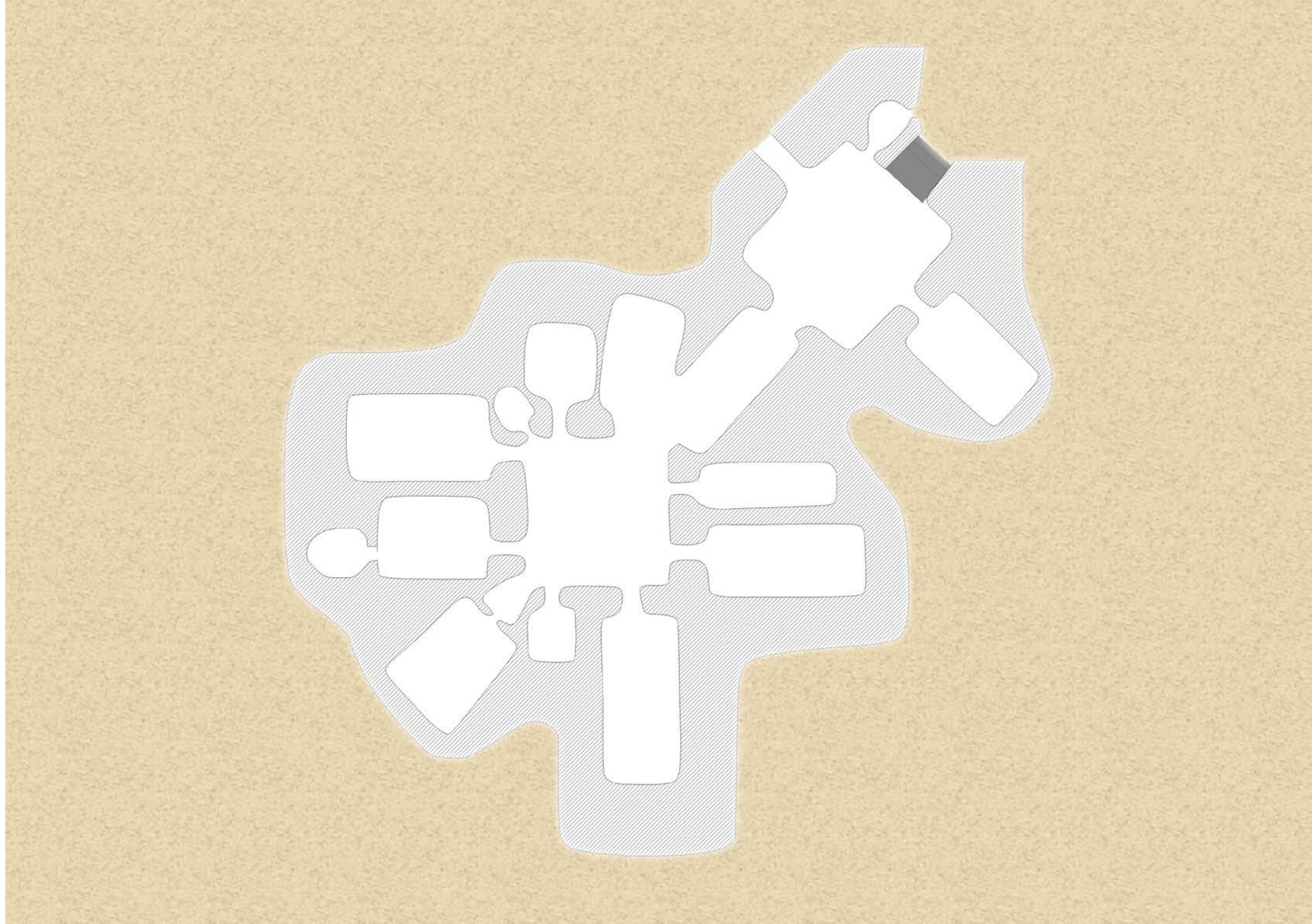


Figure 29 *Image next page - Photograph of Amdavad ni Gufa, inset plan*

4.2.2 Amdavad ni Gufa

Designed by Balkrishna Vithaldas Doshi the Amdavad ni Gufa is a subterranean Art Gallery located in Ahmedabad, India. The art gallery is spiritually inspired and makes references to the primeval caves, circles, mountains, breasts and the Buddhist stupa.[41]

Amdavad ni Gufa is built on a model of interconnecting circles and ellipses. Through its inclined domes, rounded walls, undulating floors and non-rectilinear columns, the plan does away with any centeredness. The Gufa has a built footprint of 280 sq. m however the surface area doubles owing to the convoluting planes. Buried spaces, earth mounds, raised volumes, and mosaic finish make the building energy conscious in a hot dry climate.[42]

The domes are supported by irregularly shaped inclined columns, which have been designed to resemble the trucks of trees.[43] They also have protruding snouts, which let light into the interiors of the galleries. Domes are constructed out of wire mesh and mortar floor and are completely self-supporting which are than ornamented with a tile mosaic.

Potential Advantages

• Use of curvilinear floor plan maximises usable floor area, this will be an essential tool to creating a successful habitat on Mars.

• Formally addresses the division of internal spaces when in organic and non-uniform built spaces.

• Use of concentric circles in the creation of volumes that are self-supporting during and after the construction process.

41 Jon T Lang. *A Concise History of Modern Architecture in India*. New Delhi: Permanent Black, 2002. 165.

42 David Pearson, *New Organic Architecture: The Breaking Wave*. (Berkeley: University of California Press, 2001,) 132.

43 Lang. *A Concise History of Modern Architecture in India*. 164

Figure 30 *Image right - Artist rendering of 3D printed bridge.*

4.3 3D Printing and Robotics

4.3.1 MX3D - 3D Printed Bridge

MX3D is a start-up company based out of the Netherlands, with aims to fully automate and 3D print a steel foot bridge over a canal in Amsterdam. The bridge is designed on sophisticated software, which controls a 6-axis industrial robot and can "virtually draw the bridge in the clear air, drip by drip in white hot metal, and slide forward on each newly built section."[44]

This system allows for two or more 3D printing robots at either end of the canal to print a section of the bridge and eventually meeting in the centre. This system allows the bridge to be completely self-supported and be built without any human intervention other than design.

The hardware allows the ability to "print metals, plastics and combinations of materials in virtually any format."[45] In this case the 3D printed robots "will print steel and the system will use specially-designed arms that heat up the metal to 1,500°C before welding the structure."[46]

This technology has infinite potential with applications ranging from the use in construction in dangerous environments, at dangerous heights and has possibilities of use in extra-terrestrial environments.

Potential Advantages

• Site analysis of the Martian Surface reveals that there is significant amounts of iron-oxide on the surface of Mars; this system could allow for the use of steel to be processed and used as a building material on Mars.

• This system could be applied in the construction of building apparatus such as cranes and gantries on Mars, as it will be extremely difficult to transport such equipment.

Potential Disadvantages

- Lack of mobility. Currently the design does not allow for movement other than crabbing along its own printed supports. Allowing more free range of movement will be essential to providing maximum use on the Martian surface.

- A system of turning the Martian regolith into usable steel will be needed to be developed.

44 Mike Dunphy, "World's First 3D Printed Bridge Aims to Cross Amsterdam Canal," accessed August 29, 2015, http://roadwarriorvoices.com/2015/06/20/worlds-first-3d-printed-bridge-aims-to-cross-amsterdam-canal/.

45 Sabrina Santos, "MX3D to 3D Print a Bridge in Mid-Air over Amsterdam Canal" accessed August 29 2015,http://www.archdaily.com/642329/mx3d-to-3d-print-a-bridge-in-mid-air-over-amsterdam-canal/.

46 Stu Robats, "MX3D Gets Go-ahead for 3D-printed Bridge in Amsterdam," accessed August 29, 2015. http://www.gizmag.com/mx3d-3d-printed-bridge-amsterdam/37999/.

4.3.2 Shiro Studio/ D-Shape – Radiolaria Pavilion

Complex 3D modelling tools allow a wealth of possibilities in the exploration of architectural forms. However, there has always been a lack of organisation when it comes to building such forms. “Radiolaria pavilion is a complex, free-form structure produced by using the world’s largest 3D printer.”[47] This project explores the possibility of 3D printing full scale architectural interventions. A 3 meter x 3 meter prototype was developed by using an inorganic binder, mixed with sand-stone to create the structural properties similar to that of cement.[48]

The eventual goal of the project was to create a 10 metre high pavilion. 3D printing in large scale offers the chance to explore complex digital form making techniques with the ability to construct such shapes using robotic and automated processes.

Potential Advantages

• Use of a similar strategy of construction could be applied on Mars.

• Binder mixed with the fine Martian regolith would allow the construction of a solid self-supporting structure.[49]

Potential Disadvantages

• A system of developing the regolith into useable feeder material for 3D printing would need to be developed.

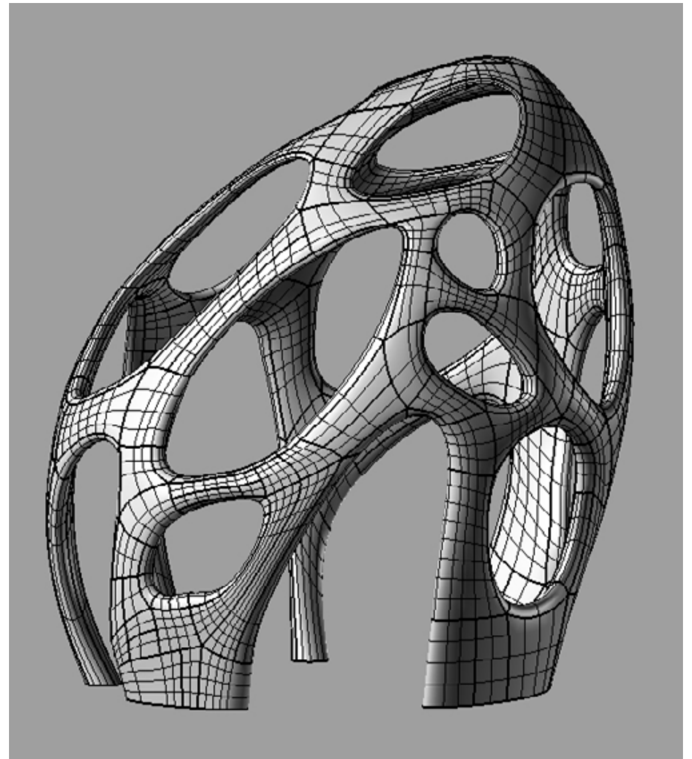
47 Dezeen, “Radiolaria pavilion by Shiro Studio,” last modified June 23, 2013, http://www.dezeen.com/2009/06/22/radiolaria-pavilion-by-shiro-studio/.

48 D Shape, “Radiolaria Pavilion: A Free-Form Structure Produced Using The World’s Largest 3D Printer,” accessed June 23, 2015, http://press.d-shape.com/index.php?flag=3.1&id=23/.

49 Martian regolith has a significant proportion of sodium dioxide in its composition. See section 5.1.6.

Figure 32 *Image right - Photograph of 1:5 scale model of 3D printed pavilion*

Figure 31 *Image below - Digital 3D model of pavilion.*



5.0 Site Analysis

Figure 33 Image previous page - Artists Impression of a Martian Sunset.

5.1 Site

A strongly functional approach to site consideration is needed. Aspects to be considered are:

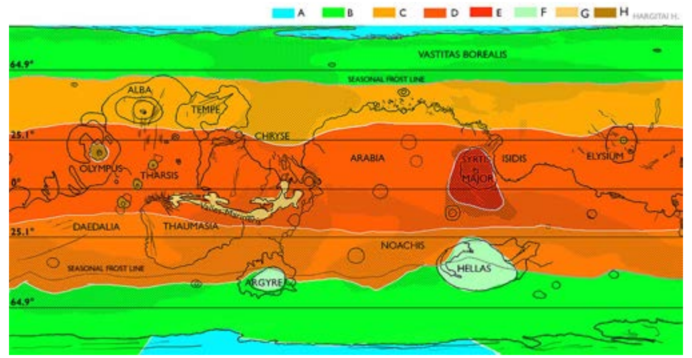
- Temperature
- Atmosphere
- Access to Water
- Sunlight
- Communication
- In-Situ Resource Use
- Geology of Surface
- Energy

The following section of this text is broken down into the above sections and a final site will be selected after analysis and deliberation.

5.1.1 Temperature

Since Mars and Earth share a similar axial tilt, a comparison using the Köppen climate classification system can be made. Mars does not have any vegetation and rainfall. It is important to note that this comparison is only based on seasonal temperature variations and not the vegetation and precipitation associated with each classification. This simplified comparison makes the climate system of Mars easier to understand. Although there are some seasonal similarities in temperature between Earth and Mars, the extremes are much greater. Tropical areas of Mars in the summer periods can experience daytime temperatures of 20°C.[50] Averages are recorded at -63°C and an absolute minimum of -140°C.[51] Winter temperatures are bitterly cold with highs only of -35°C.[52]

Figure 34 Image below - Mars Global Climate Zones - seasonal climatic zones of the planet using the Köppen climate classification system

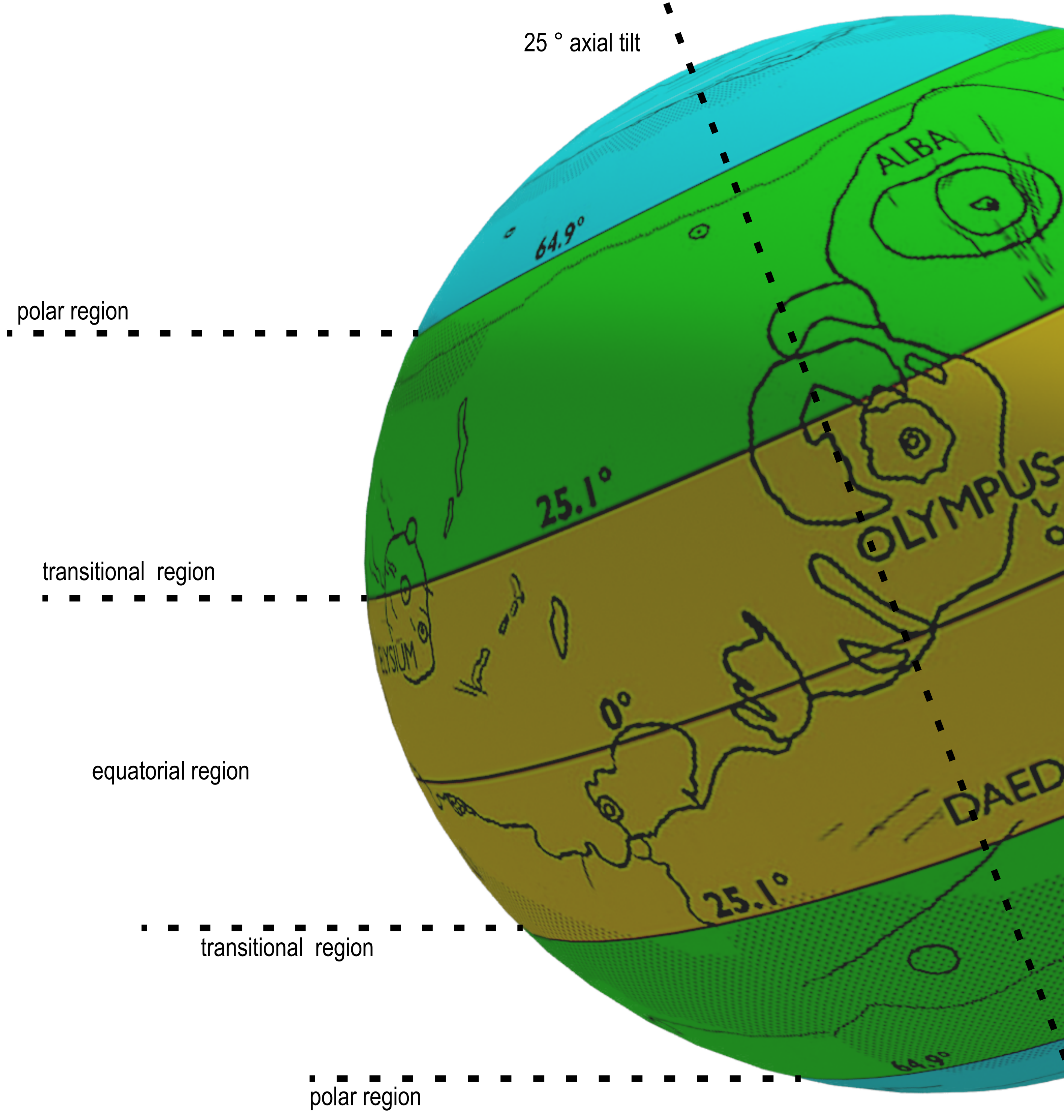


50 Glen Elert, "Temperature on the Surface of Mars," accessed March 16, 2015, http://hypertextbook.com/facts/2001/AlbertEydelman.shtml.

51 MarsNews.com, "Overview," Newswire for The New Frontier, accessed March 16, 2015, http://www.marsnews.com/focus/mars/.

52 Ibid

Figure 35 Image right - Global Climatic Regions - of Mars



- A=Glacial (permanent ice cap)
- B=Polar (covered by frost during the winter which sublimates during the summer)
- C=North (mild) Transitional (Ca) and C South (extreme) Transitional (Cb)
- D= Tropical
- E= Low albedo tropical
- F= Subpolar Lowland (Basins)

Figure 36 *Image left - Artist Impression of the Thin Martian Atmosphere*

5.1.2 Atmosphere

The Martian atmosphere is extremely thin in comparison to that of Earth. It is approximately 100 times thinner than that of Earth.[53] The Martian atmosphere is composed of:

Carbon-dioxide	95.32%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.13%
Carbon-Monoxide	0.08%

Table 2 *Above - Breakdown of Martian Atmposhere - Source* Tim Sharp, "Mars' Atmosphere: Composition, Climate & Weather," accessed March 18, 2015, http://www.space.com/16903-mars-

53 Tim Sharp, "Mars' Atmosphere: Composition, Climate & Weather," accessed March 18, 2015, http://www.space.com/16903-mars-atmosphere-climate-weather.html

Although the atmosphere is extremely thin, it is dense enough for strong winds to occur. The Martian surface is known to have extremely strong winds and is capable of having huge dust storms that are able to blanket the whole planet for months.[54] Wind speeds of between 50 kilometres an hour and 100 kilometres an hour have been recorded.[55] Since the Martian atmosphere is only 1% of that of Earth the dynamic pressure created by a 100 kilometre an hour wind storm is only equal to that of a 10 kilometre an hour breeze on Earth.[56] However, recent studies have indicated that strong winds and dust storms are lessening for reasons unknown.[57]

54 Ibid
55 Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Red Planet and why we Must.*142.
56 Ibid. 143.

57 NASA Quest, "Mars Facts," NASA, accessed March 18, 2015, http://quest.nasa.gov/aero/planetary/mars.html.

5.1.3 Access to Water

Water is one of the most important resources that will be required by Martian settlers. The dry and dusty surface of Mars is littered with evidence that water once flowed on the surface in the form of rivers and the planet even had large oceans at one stage.[58] At present no liquid water exists because of the extreme low temperatures and low atmospheric pressure. Transporting water for the early settlers may seem like a feasible option but in the long run this is not sustainable.

However there are large quantities of frozen water at the poles of the planet. About five million cubic kilometers of ice has been identified on the planet at present and possibly even more is locked away in the subsurface regions of Mars.[59] Water is not only confined to the polar regions of Mars studies suggest that equatorial regions have ice trapped beneath the surface in lesser quantities (Figure 37).

Research conducted at the Australian National University has drawn conclusions that up to 3.2% of the Martian volume can be fit for human habitation.[60]

Martian soil is another potential source of water. Research indicates that the top one meter of regolilth has between 8 to 10 % water and tests have proven there is chemically bound water in the soil.[61] This has since been proven by the Mars Odyssey obiter. This chemically bound water can be extracted by heating it to appropriate temperatures and through other chemical processes. A site that is able to easily access this in-situ resource will favour production of food and production and extraction of oxygen.

58 University of Colorado at Boulder. "Ancient Ocean may Have Covered Third of Mars." ScienceDaily, accessed March 16, 2015. www.sciencedaily.com/releases/2010/06/100613181245.htm.

59 Philip R. Christensen, "Water at the Poles and in Permafrost Regions of Mars". *GeoScienceWorld Elements 3*, (2006): 151–155.

60 Eriita G. Jones, Charles H. Lineweaver and Jonathan D. Clarke, "An Extensive Phase Space for the Potential Martian Biosphere," *Astrobiology*, Vol. 11 (2011). 1017

61 Bret G Drake, ed., *Human Exploration of Mars Design Reference Architecture 5.0* (Washington DC: NASA, 2009), 73.

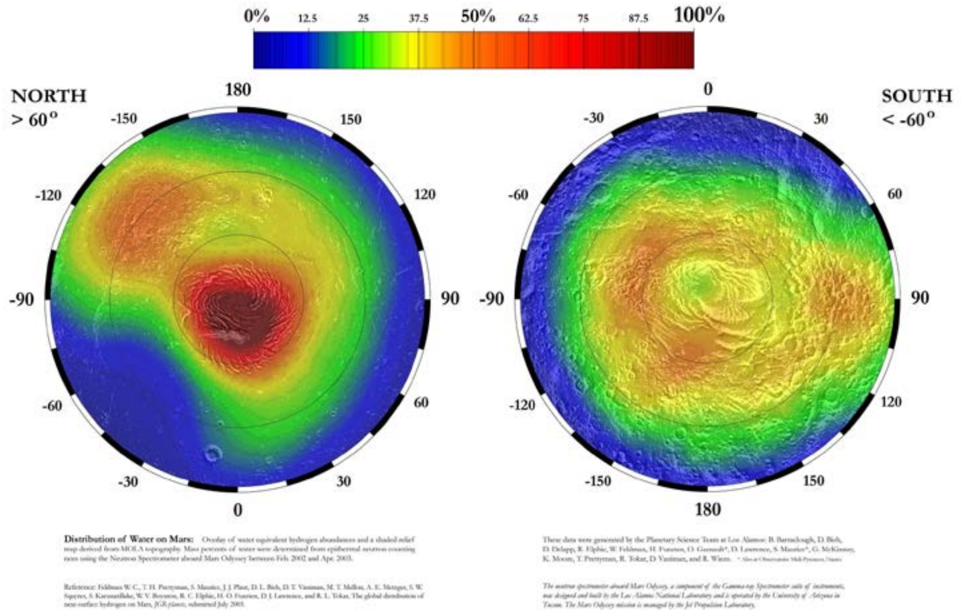


Figure 37 *Image above - Water Equivalent Hydrogen Abundance - showing percentage H_2O content in the higher latitudes of Mars*

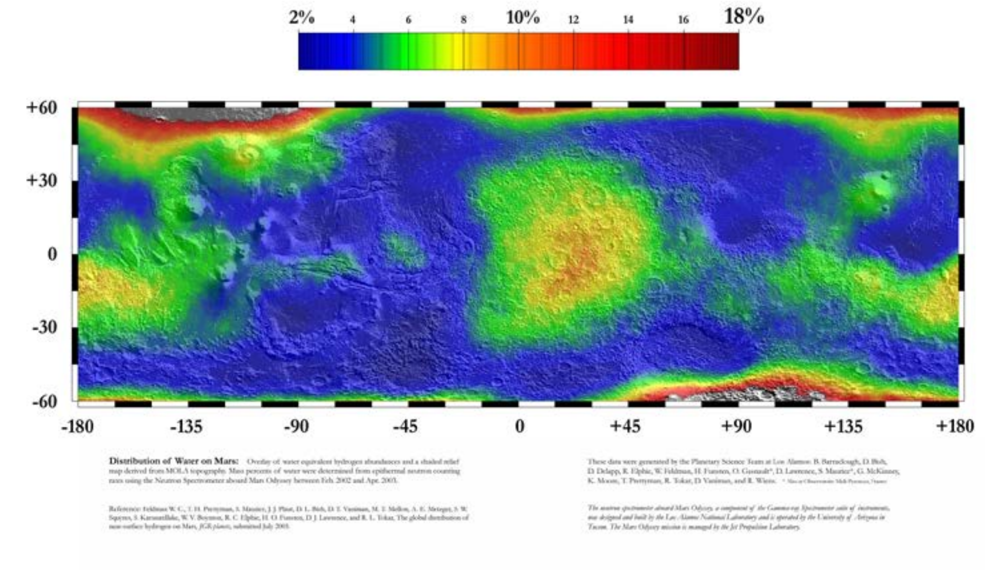


Figure 38 *Image above - Water Equivalent Hydrogen Abundance - showing percentage H_2O content in the lower latitudes of Mars*

5.1.4 Solar Cycles and Radiation

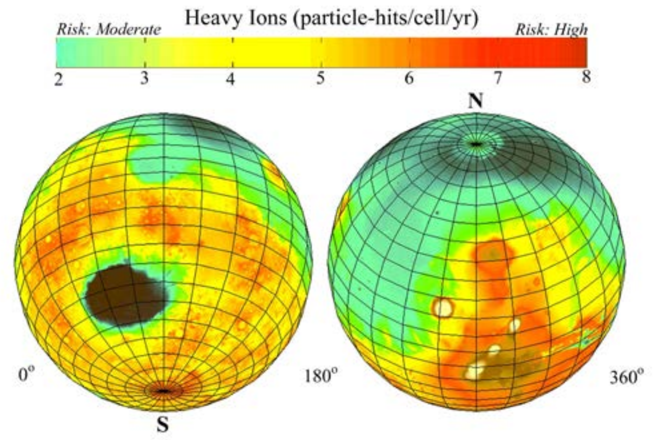


Figure 39 *Image above - Mars Cosmic Ray Environment - showing cosmic ray exposure on a planetary scale.*

The sun looks about 62% of the size as it would from Earth and Mars only receives about 40% of the light.[62] An average day on the Martian surface lasts 24 hours and 37 minutes[63] (often referred to as Sols) and takes about 669 sols to orbit the sun.[64]

Solar Radiation is one of the most significant dangers posed to humans on Mars. Mars does not have a global magnetic field and coupled with a very thin atmosphere is exposed to a very large amount of ionizing radiation. It is important to note "the planet's bulk shields against half of the cosmic radiation that is received in space"[65]

62 Richard Gary, "Watch the sun set on Mars: Opportunity rover captures the red planets deep blue sky as our star 'dips' below the horizon," accessed March 20, 2015, http://www.dailymail.co.uk/sciencetech/article-2967033/Watch-sun-set-MARS-Opportunity-rover-captures-red-planet-s-deep-blue-sky-star-dips-horizon.html
63 Ibid
64 Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Red Planet and why we Must.* 181.

65 Drake, *Human Exploration of Mars Design Reference Architecture* 5.0, 65.

5.1.5 Communication

Communication between Earth and Mars is fairly straight forward. There are a number of satellites already in orbit around the planet and this number is only expected to increase. However, due to the significant distance between Earth and Mars - there will be a considerable delay in communication. This means real time live communication might not be practical. Video messages and data exchange will not incur any of these issues and should be an appropriate alternative. NASA is developing technologies that could reduce time delays and improve efficiency in communications between the two planets.[66]

The most significant obstacle is during a solar conjunction when Earth and Mars are separated by the Sun. Solar conjunction lasts for approximately 2 weeks to a month, during a two year cycle, radiation let out by the Sun interferes with radio waves preventing communication.

66 Drake, *Human Exploration of Mars Design Reference Architecture 5.0,* 65.

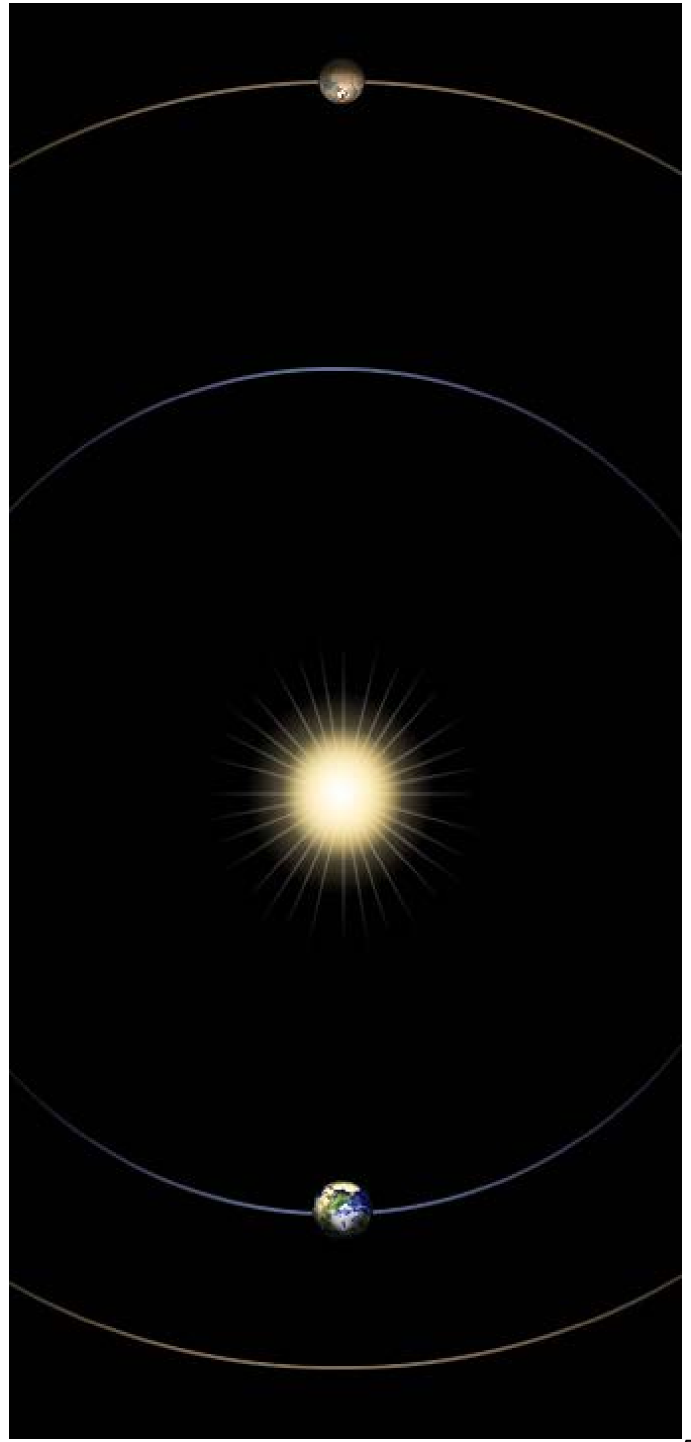


Figure 40 *Image right - The phenomenon of Solar conjunction*

Figure 41 *Image left - The processes that will be required to produce usable resources using in-situ material.*

5.1.6 In-Situ Resource Use

Local resource utilisation will be a very important consideration if a permanent human settlement is to be established on Mars. It is inconceivable to think that raw building materials will be transported from Earth. The first settlers will no doubt occupy environments that were constructed on Earth. After a significant amount of time passes, these very settlers will transform Martian raw materials into useful resources.

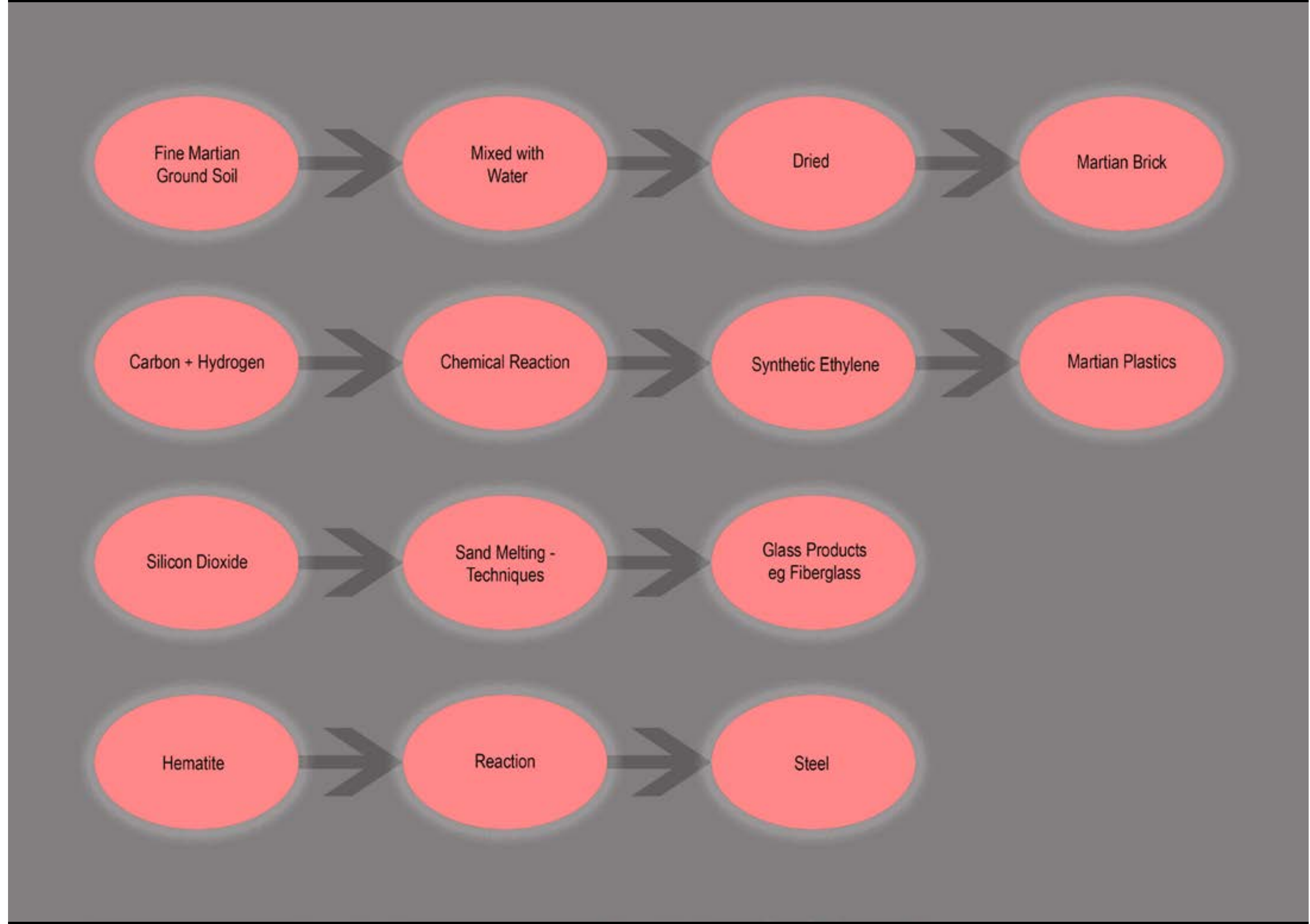
The planetary surface offers a lot of promise to source all the raw ingredients required to make these materials. One of the most optimum material for building the first large structures on Mars is brick.[67] The surface of Mars is covered in fine, iron-rich clay like dust, once mixed with water and baked, it could prove to be a valuable building material. Bricks on Earth have been used to make structures in compression for thousands of years, which still stand today.

Plastics can be manufactured on Mars because like Earth it has all the raw materials necessary. The planet has an abundant supply of carbon and hydrogen - the key chemical components used to manufacture plastics. Glass and glass products like fibre glass will also be easily produced on Mars. Both Viking missions noted significant quantities of silicon dioxide in the Martian soil. Through sand-melting techniques that have been used on Earth for thousands of years it will be possible to manufacture various glass products for the first settlers to use as a building material.

Mars is considerably richer than Earth when it comes to Metallurgy. This will be very important if a long term habitation is to be established. By far the most abundant industrial material that is present on Mars is iron. In fact it is so abundant on Mars that it causes the planet to become red. Through the same method of making usable steel on Earth, Martians can produce vast amounts of steel for use in construction.

67 Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Red Planet and why we Must.* 189-190

Aluminium on Mars makes up about 4% of the Martian soil by weight. However, the industrial process to make aluminium is quite complex, and potentially very expensive. Therefore, aluminium would not be a widely used building element and mostly used for very specific application.



5.1.7 Geology of Mars

Mars has the four essential components for organic matter to grow - hydrogen, carbon, nitrogen, and oxygen. However the main question is - how fertile is Martian soil? Very - is the short answer. Researchers that have conducted experiments with analogue Martian soil have had surprising results. In simulated environments of Mars, various plant species including food plants blossomed.[68]

Chemical composition of Martian soil also shows that it is a perfect substitute for Earth soils to grow plants. There is also evidence to suggest that the soil is considerably better than that of Earths in some respect. Figure 38 on the next page describes the Geological condition of the planet at present in a very generalised way.

Most of the planet is covered in the evidence of ancient volcanic activity. The planet features extensive lava flow, lava plains and the largest volcano known in the Solar System. There is also significant quantities of frozen ice at both poles. Very hard Basalt is scattered through the entire planet.

68 Divya Avasthy, "Martian Soil Suitable For Growing Plants, Researchers Find," accessed March 23, 2015, http://www.ibtimes.co.uk/martian-soil-suitable-growing-plants-researchers-find-1432658.

Figure 42 *Image this page - Martian Soil Analogue*

Table 3 *Below - Percentage breakdown of Martian soil composition* - Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Red Planet and why we Must.* 213

Element	Terrestrial Soil Average	Martian Soil Average (est.)
Nitrogen	0.14%	Unkown
Phosphorus	0.06%	0.30%
Potassium	0.83%	0.08%
Calcium	1.37%	4.10%
Magnesium	0.50%	3.60%
Sulfur	0.07%	2.90%
Iron	3.80%	15.00%
Manganese	0.06%	0.40%
Zinc	50 ppm	72 ppm
Copper	30 ppm	40 ppm
Boron	10 ppm	Unkown
Molybdenum	2 ppm	0.4 ppm

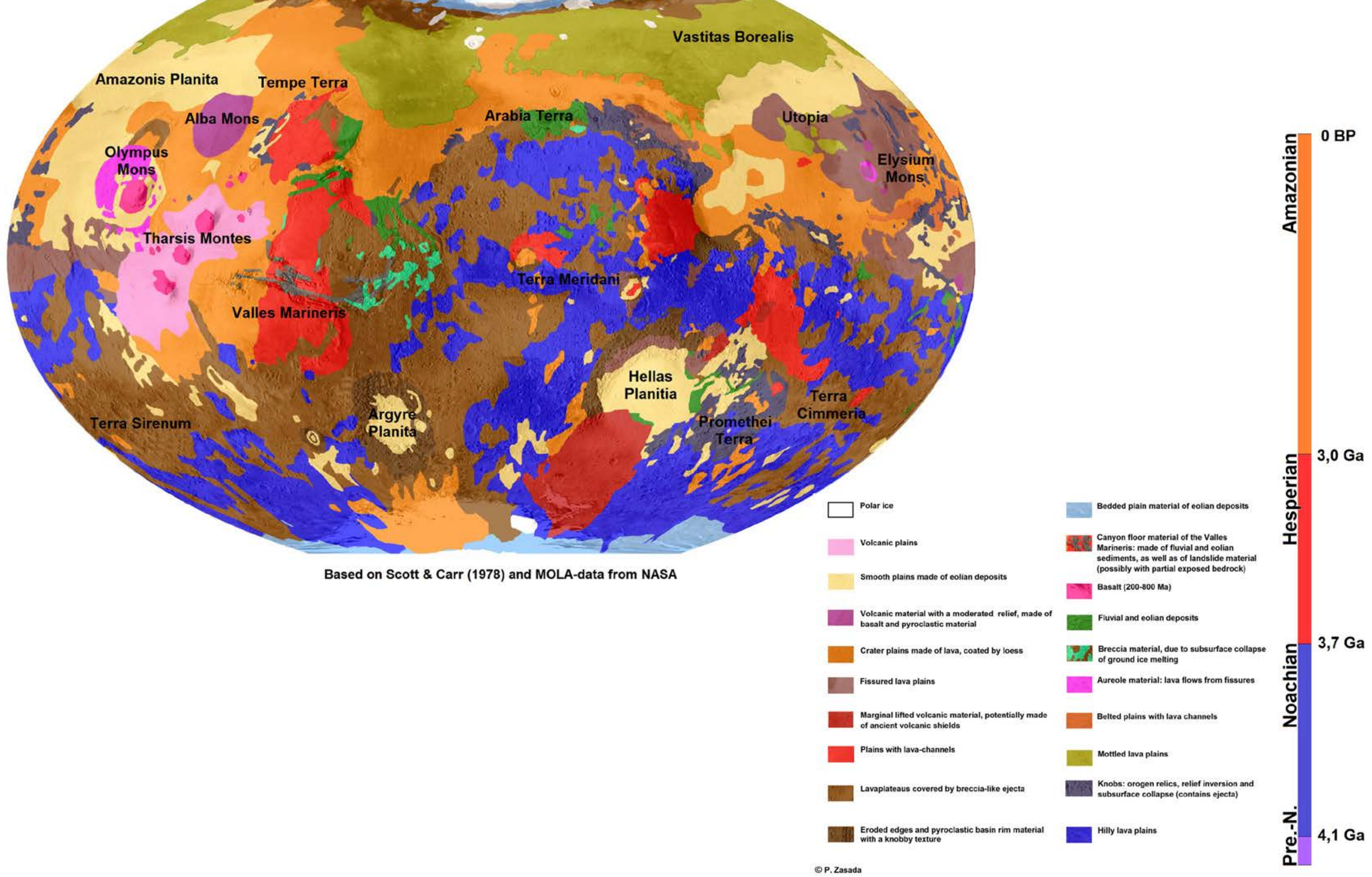


Figure 43 *Image this page - Generalised Geological Map of Mars - explains the varity of geological situation at present on Mars.*

Figure 44 *Images next page - variety of methods that can be used to produce energy on Mars. From left to right - wind energy, solar energy and geothermal energy*

5.1.8 Energy

It is clear that without large amounts of electrical and thermal power a Martian base will not exist. Electrical power will be required for basic lighting and equipment use on the colony. Thermal power will be required as a precursor to the ability to produce and manufacture in-situ supplies as described in 5.1.6.

Most of the Earths power at present comes from hydroelectric, fossil fuels combustion and nuclear methods. Geothermal, solar and wind are also widely used to produce power today, although in a much lesser quantity. The only way a self-sustaining colony can be established on Mars if it is one that is entirely self-sufficient in its energy needs. Importing material from Earth to power the colony will be impractical. On Mars, hydroelectric and fossil fuels are impossible to use to produce energy. On the other hand, it is possible to use solar and wind power to generate the energy required to power the base.

A photovoltaic system that can provide 5kW of power would weigh about 3000 kilograms and can be transported from Earth.[69] For a long term solution Photovoltaic systems can be produced from existing resources on the planet, namely the presence of silicon and aluminium.[70]

Another source of energy could be from harvesting the wind. Wind energy has been used on Earth for many hundreds of years and can be implemented on Mars to provide substantial amounts of energy. With such vast amounts of past volcanic activity throughout the planet, there is a lot of indicators to suggest a high likelihood of geo-thermal activity present on the planet. Although hypothetical at the moment, geothermal activity may in fact be present on the planet. If so, using the planets own internal heat to produce energy will be entirely possible for the colony.

69 Drake, *Human Exploration of Mars Design Reference Architecture 5.0*, 60.
70 Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Read Planet and Why we Must*, 224.

Figure 45 *Image previous page - Aeolis Mons - Photograph of Mount Sharp taken from the Curiosity Rover*

Figure 46 *Image this page - location of the Gale Crater on the planet*

5.2 Site Description

The chosen site for the colony is the Gale Crater. Gale is aptly named after Australian amateur astronomer, Walter Frederick Gale who first observed it. The crater is located just south of the equator at exactly 5.4°S 137.8°E and is 154 kilometres wide and has a mountain in the centre. Aeolis Mons (henceforth referred to as Mount Sharp as it is more commonly known) rises 5.5 kilometres from the northern crater base and 4.5 km above the southern crater base.

At present Gale is host to a terrestrial visitor. NASA's Mars Science Laboratory (MSL), Curiosity, has been at the site exploring the area since August 5th 2012.[71] NASA chose Gale as the landing site because it had a lot of signs to indicate that water was present over its history. A hypothesise confirmed when scientists reviled that Gale is in fact an ancient lake bed.[72]

71 Mike Wall, "Touchodown! Huge NASA Rover Lands on Mars," accessed March 25, 2015, http://www.space.com/16932-mars-rover-curiosity-landing-success.html.

72 Ibid

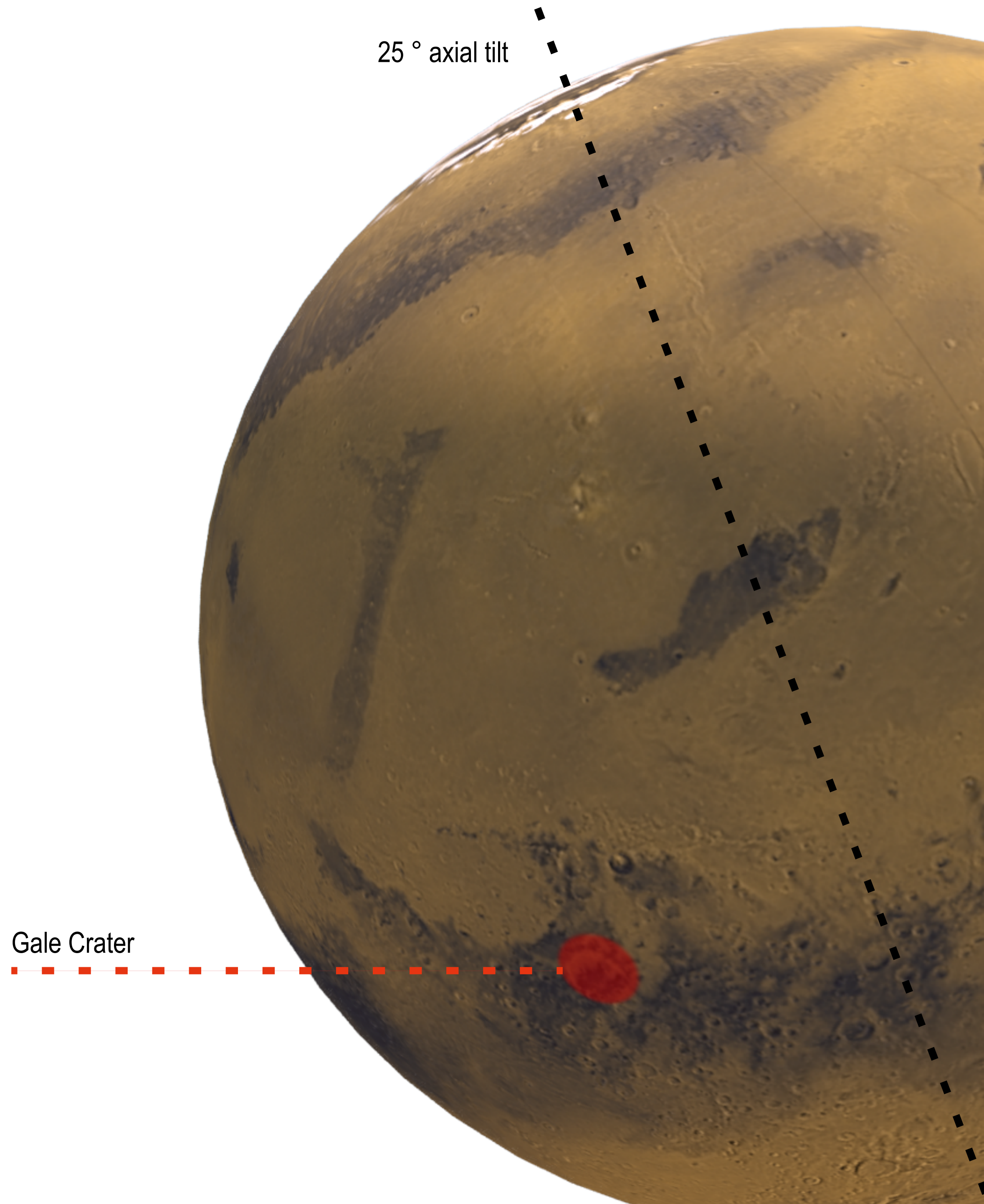


Figure 47 *Image next page - Artists impression of the Gale Crater.*

Figure 48 *Image this page - oblique view of the Gale Crater with section markers and longitudes and latitudes indicated*

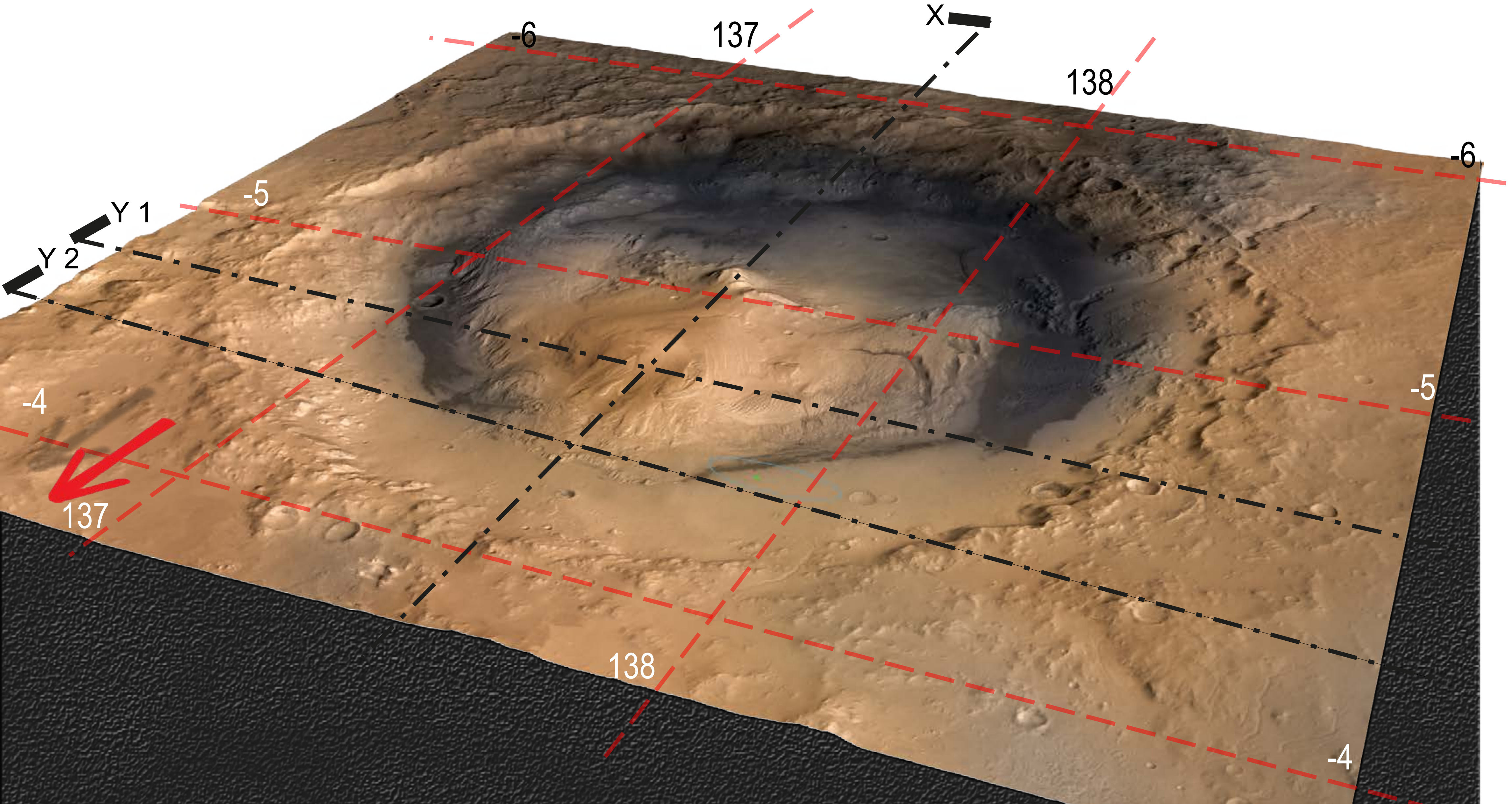


Figure 49 *Image left - Section Y-1 of the Gale Crater*

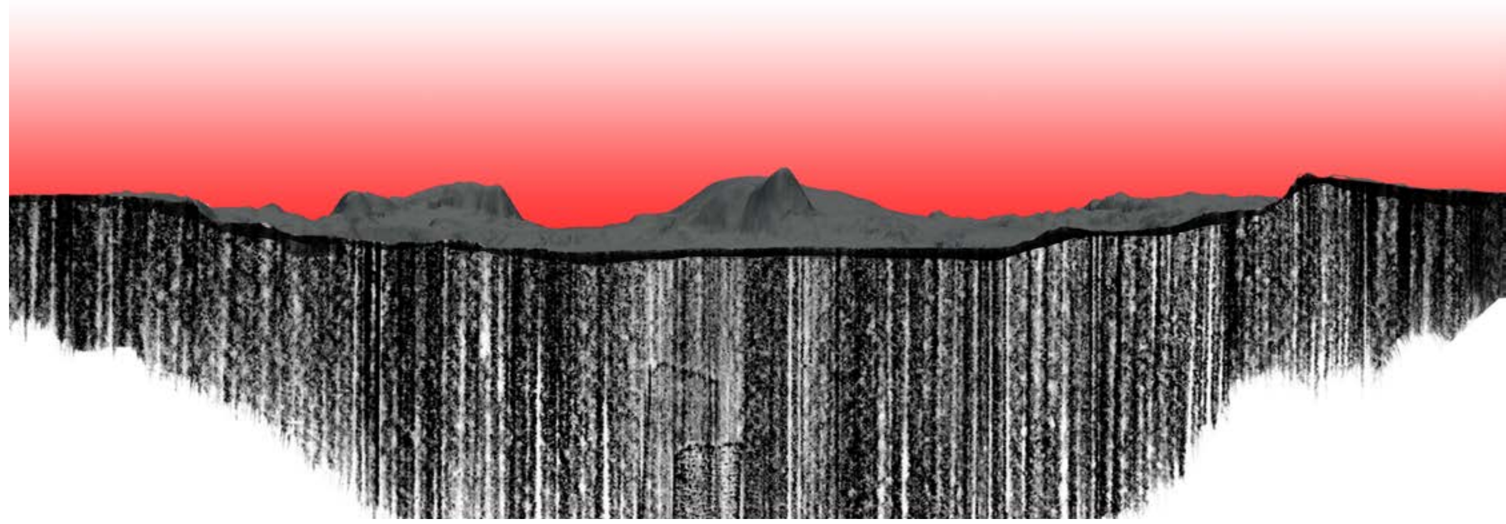
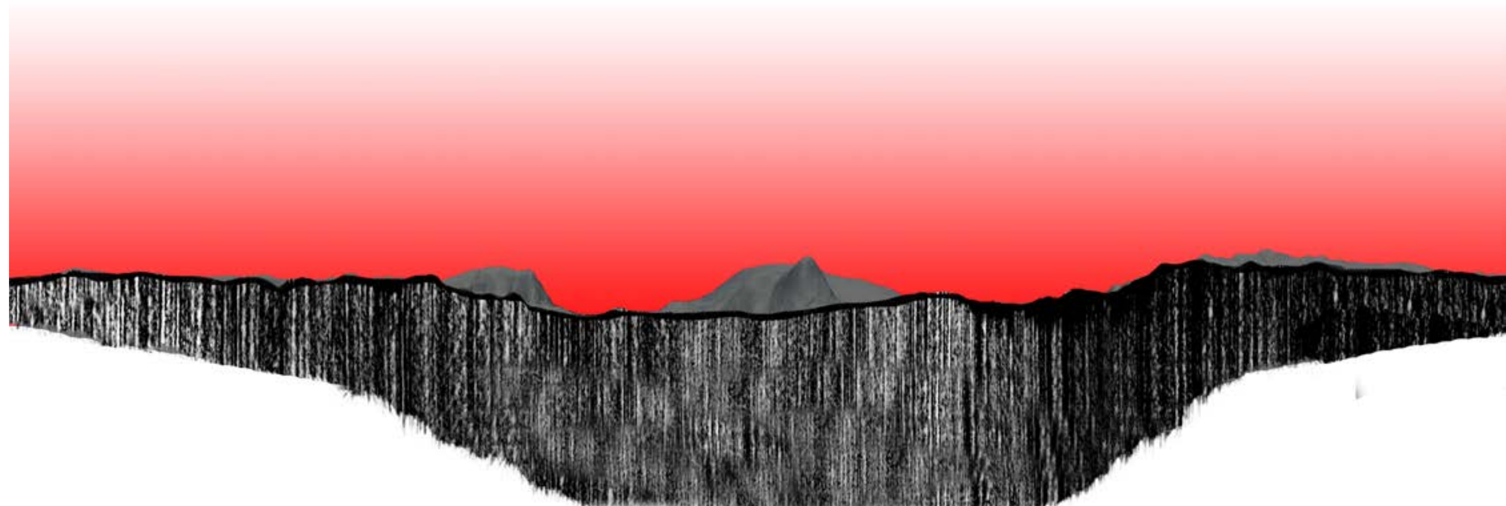


Figure 50 *Image left - Section Y-2 of the Gale Crater*



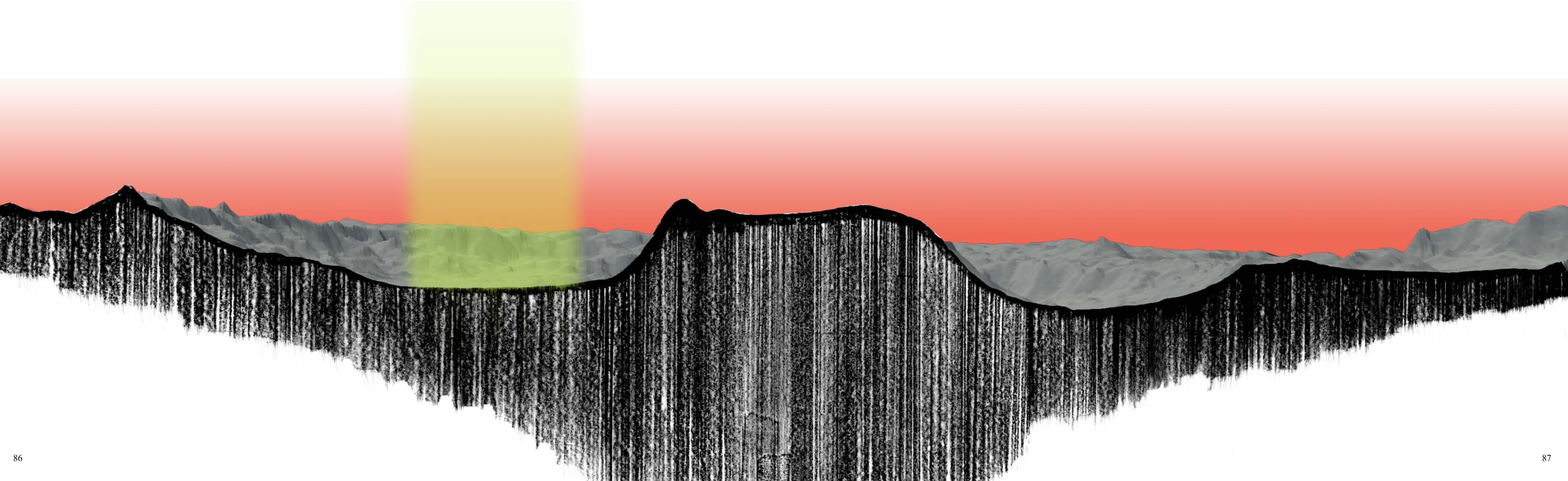


Figure 51 *Image previous page - Section X of the Gale Crater*

5.2.2 Why Gale?

Firstly, temperature. Gale experiences average temperatures of a high of 0°C and low of -80°C.[73] Two Antarctic stations built and in use today experience these temperatures on a regular basis. Both the Concordia Station and Amundsen-Scott South Pole Station experience highs far lower than in the Gale crater and lows of relatively similar temperatures.[74]

Second, Water. As discussed earlier, the key to survival on the planet will be access to water. The Gale crater, is thought to be an ancient lake bed and the Martian regolith has between 1.5 to 3% by weight of water chemically bound in it.[75 76] It is highly likely, regolith around the Equator may not have such a high water content. Therefore Gale provides a better opportunity to access this in-situ resource, and is a better alternative as opposed to areas around the Equator.

Third, Radiation Protection. As a rule of thumb the best way to provide Radiation Protection on a planetary scale is an increase in atmospheric pressure. Therefore, the thicker the atmosphere the better the protection. Earth has a mean sea level atmospheric pressure of about 14 psi. The mean on Mars is about 0.087 psi. However, the pressure at Gale averages 0.12 psi.[77] Although significantly lower it provides more protection than on the surface of Mars. Limiting direct Sun light by using depth will create added protection. The shadow of Mount Sharp and the edge of the crater rim, will provide added shielding. However, architectural exploration into providing better protection must be looked into. The added depth also increases the gravitational pull marginally in the region.

Fourth, Communication. Communication from the crater is already established. Curiosity has been communicating from Gale to Earth since its mission started albeit with a delay.

Fifth, In Situ Resource Use. As described in 5.1.6, Gale will be able to cater for all the resources outlined in the description. Mineral composition of Martian regolith is similar throughout out the planet. The architecture will be a product of these resources that are available.

Sixth Geology. As with the point above. Geology of the planet remains largely the same and issues that arise will be addressed through the architectural intervention.

Finally, Energy. Energy requirements of the colony will be met through solar and wind energy. Both of which will be able to harvested on the edge of the crater.

73 Rover Environmental Monitoring Station (REMS) "Temperature range at Gale Crater," accessed March 25, 2013, http://curiosityrover.com/rems/.

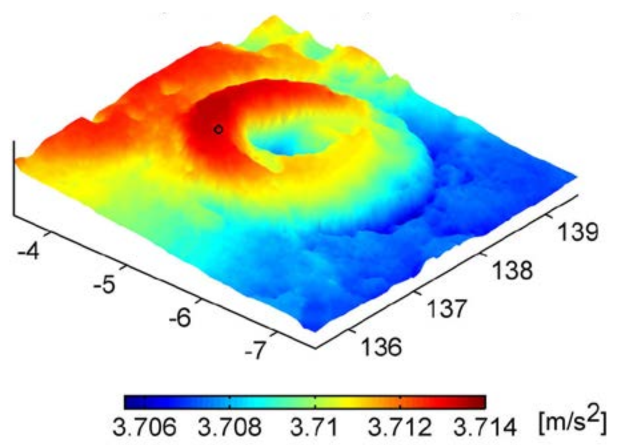
74 Ruth Slavid, *Extreme Architecture: Building for Challenging Environments* (London: Laurence King Publishing, 2009), 186.

75 Kenneth Chang, "Hitting Pay Dirt on Mars," The New York Times, accessed March 25, 2015, http://www.nytimes.com/2013/10/01/science/space/hitting-pay-dirt-on-mars.html?_r=0.

76 Josh Lieberman, "Mars Water Found: Curiosity Rover Uncovers 'Abundant, Easily Accessible' Water In Martian Soil," The International Science Times, accessed March 25, 2015, http://www.isciencetimes.com/articles/6131/20130926/mars-water-soil-nasa-curiosity-rover-martian.html.

77 Rover Environmental Monitoring Station (REMS) "Atmospheric pressure at Gale Crater" accessed March 25, 2013, http://curiosityrover.com/rems/.

Figure 52 *Image below - Gravity Acceleration - Image describing the diffrence in the pull of Gravity in the Gale Crater.*



6.0 Ratio Analysis

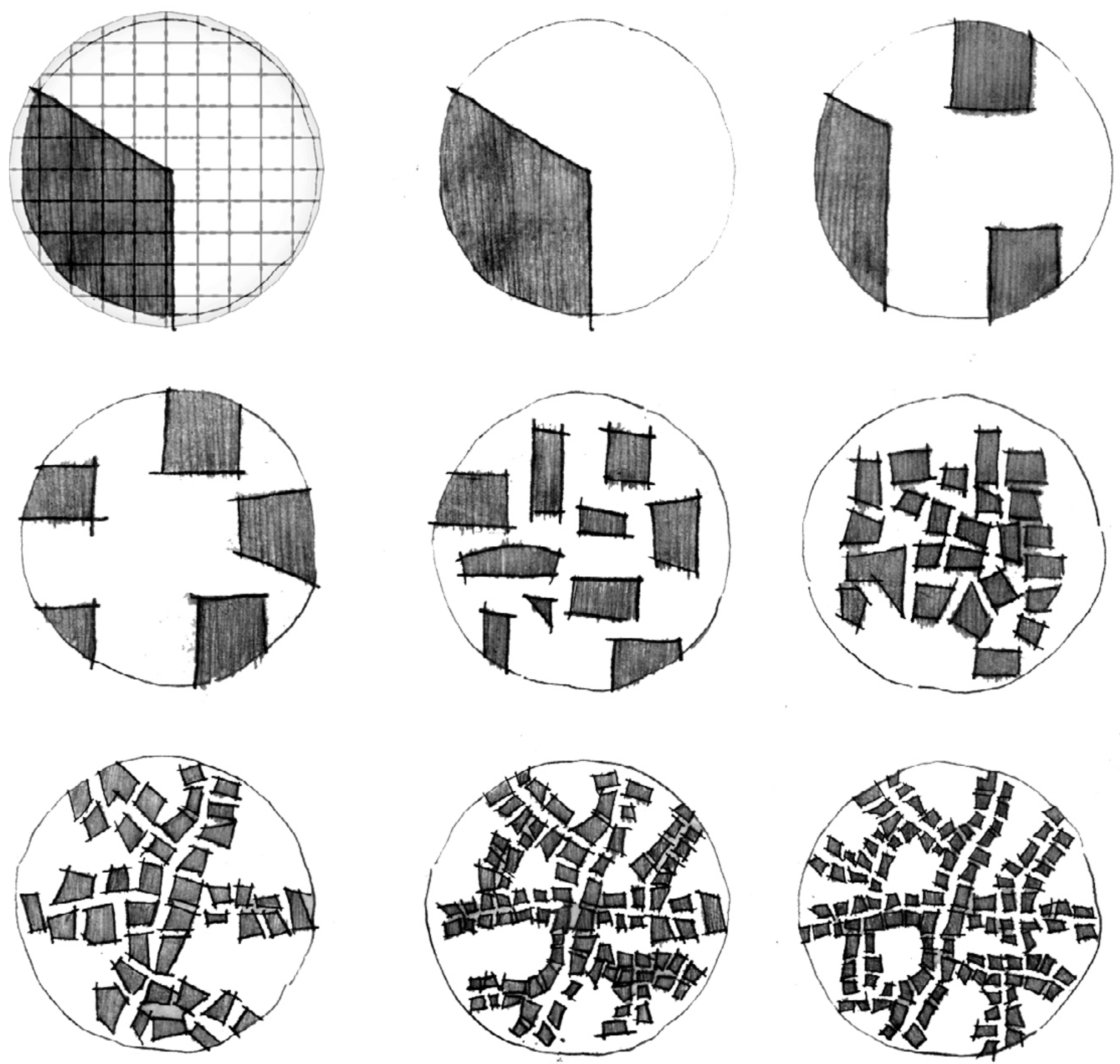


Figure 53 *Image previous - Initial iterations of Ratios*

Table 4 - *Below - Calculation of area from examples*

6.1 Ratio Analysis

In order to determine an appropriate relationship between built spaces and open spaces an analysis of terrestrial examples was done. This analysis focuses on communal and self-sufficient communities. It was deemed necessary to do so in order to derive a tangible ratio.

The two communities that were explored and analysed were; Arcosanti in Arizona, USA and Solar City in Linz, Austria.

Arcosanti – Arizona, USA

Master planned by Paolo Soleri, Arcosanti is an experimental township planned and partly constructed with the theory of "arcology" – a combination of architecture and ecology.[78] The project is a relevant example in the context of building with minimal impact to the environment and promote a self-sufficient living, and working environment with emphasis on communal living. Self-sufficiency will be of paramount importance on Mars, therefore this example will provide valuable data in terms of ratios and relationships of built forms. The project was designed for a total of 5000 citizens eventually occupying the experimental township.[79]

SolarCity – Linz, Austria

Master planned by Austrian urban planner, Prof. Roland Rainer, SolarCity, is a satellite township of Linz constructed with design strategies of ecological and sustainable housing.[80] Similar to the last example, this project aims to provide energy efficiency in a community in particular utilising solar energy. The master planning takes on board design principles of solar architecture, utilisation of active and passive solar energy, emphasising the aspects of nature, social integration, social warmth and social energy.[81] These principles will be of paramount importance in a community on Mars and as such this project will provide data in order to determine the ratios and relationships required to maintain a self-sustaining community. The project at present caters to a population of 4000 people.

As discussed in section 3.2, this research project will develop a system of organic growth, to provide a tool set in the eventual expansion of the Martian colony. As such the data that the above two examples provide concludes in a built to open space ratio of 40% to 60 %. The analysis also provides for an appropriate scale for a Martian colony. This scale comes in the form of the combination and averages of the two examples. The proposed Martian master plan will sustain growth for a community of 4500 people on an area of 38 hectares. As discussed in section 3.1 MarsOne's proposal only provides 50.5 sqm per person living area, which was deemed to be too confining, therefore based on the averages of the analysis an area of 90 sqm per person is determined and will be used as the basis of all further detailed design development.

The analysis also covers the ratios of specific programmes in each of the cases studied. These percentages will be applied in the detailed design stage.

	People	Area SQM	Average per Person
Arcosanti	5000	174,201.83	34.840
Solar City	4000	594,468.00	148.617
Martian Masterplan	**4500**	**384,334.92**	**91.73**

78 Rory Stott. "Spotlight: Paolo Soleri," accessed September 10 2015, http://www.archdaily.com/391428/happy-birthday-paolo-soleri/.
79 Ibid

80 Jurgen Breuste and Jurgen Riepel. "Solarcity Linz/Austria - A European Example for Urban Ecological Settlements and Its Ecological Evaluation," accessed June 7, 2015. http://www.oikodomos.org/workspaces/app/webroot/files/references/text/sozcelik_15_solar_city.pdf.
81 Ibid

Figure 56 *Image below - Analysis of Solar City*

Figure 55 *Image below - Chart of average function distribution*

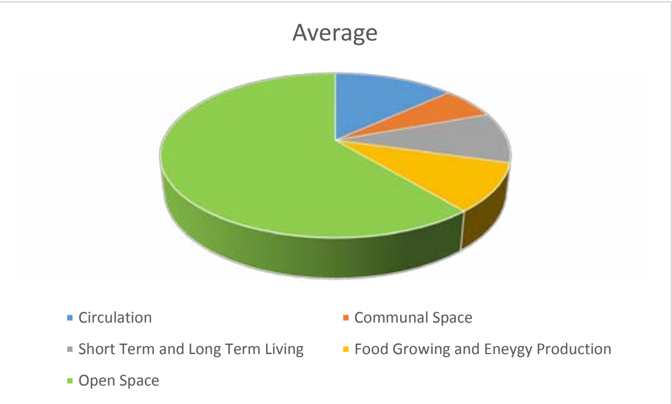
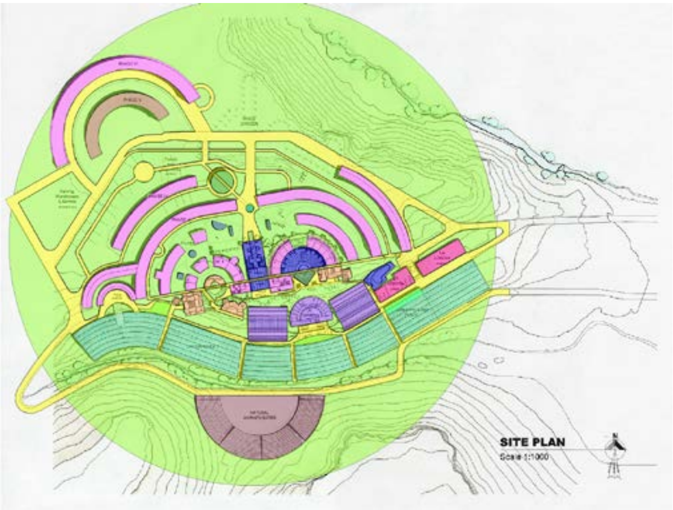


Figure 54 *Image below - Analysis of Arcosanti*



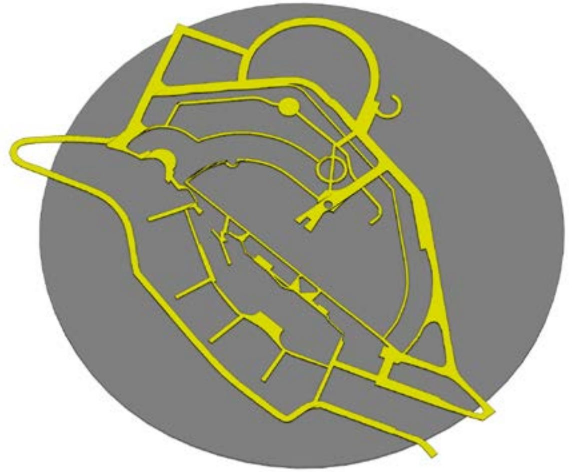


Figure 57 *Image above - Arcosanti - Circulation Space accounts for 13.5% of the total site on the ground plane.*

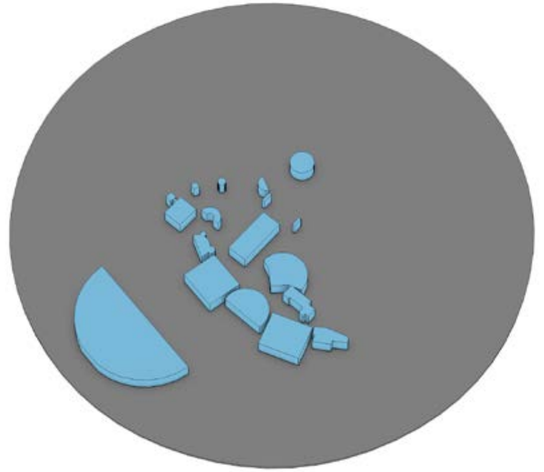


Figure 58 *Image above - Arcosanti - Communal Space accounts for 7.95% of the total site on the ground plane*

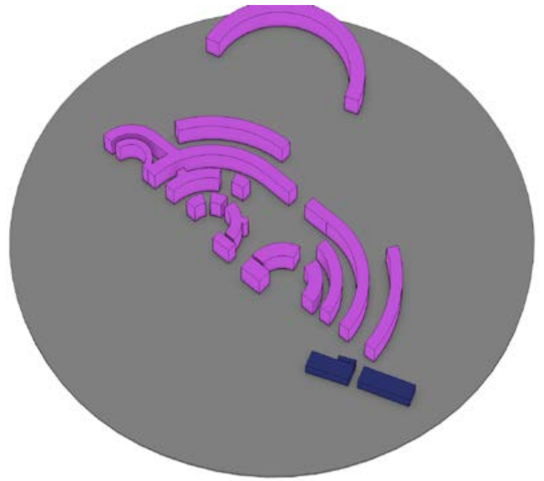


Figure 59 *Image above - Arcosanti - Long Term and Short Term Living Space accounts for 8.5 % of the total site on the ground plane*

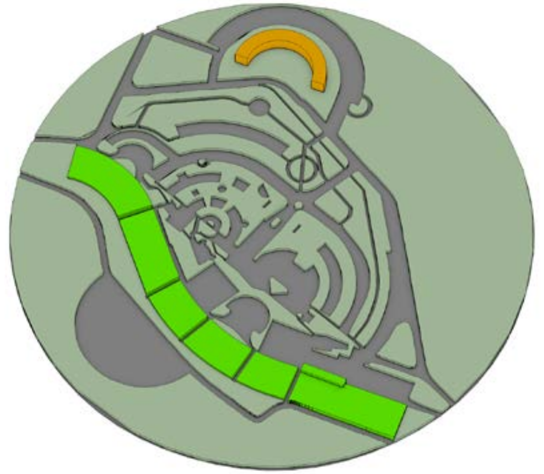


Figure 60 *Image above - Arcosanti - Food Growing and Energy producing space accounts for 8.5% of the total site on the ground plane while open space accounts for 61.55% of the site.*

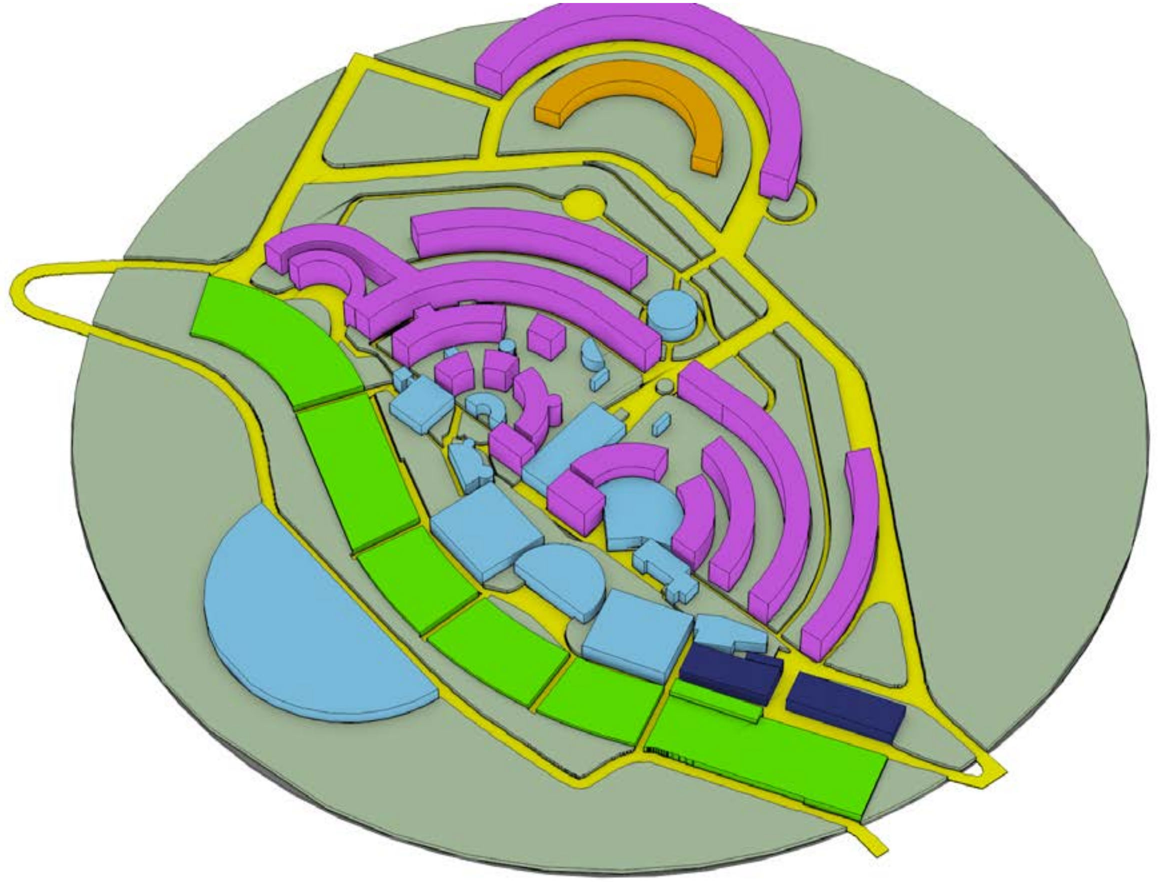


Figure 61 *Image above - Arcosanti - Total site. Extants of site Area:17.5 hectares, provides 35 sqm of living area per person on the ground plane.*

Figure 62 *Image above - Solar City Linz - Circulation Space accounts for 13% of the total site on the ground plane.*

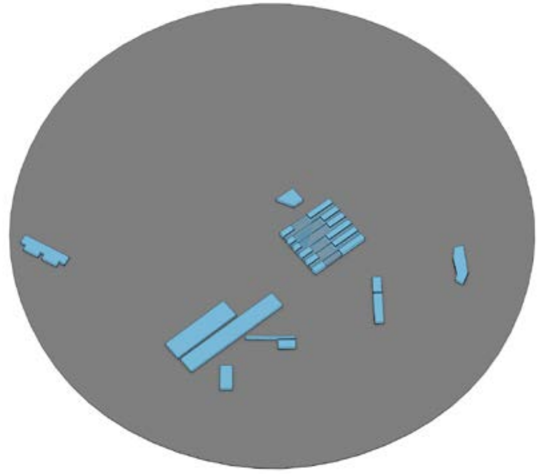


Figure 63 *Image above - Solar City Linz - Communal Space accounts for 4.4% of the total site on the ground plane*

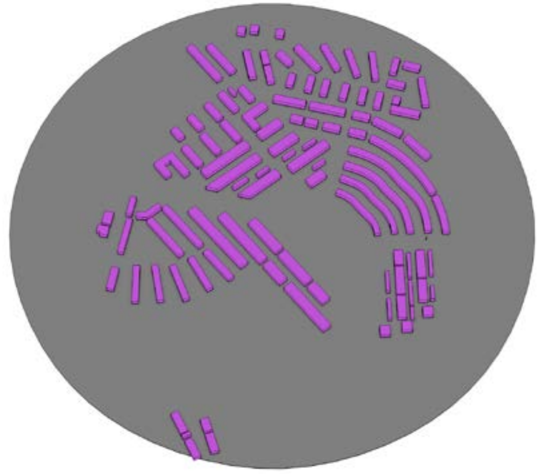


Figure 64 *Image above - Solar City - Long Term and Short Term Living Space accounts for 11.4% of the total site on the ground plane*

Figure 65 *Image above - Solar City - Food Growing and Energy producing space accounts for 10.6% of the total site on the ground plane while open space accounts for 60.5% of the site.*

Figure 66 *Image above - Solar City - Total site. Extants of site, Area: 59.4 hectares, provides 148 sqm of living area per person on the ground plane.*

7.0 Design Process

Figure 67 *Image previous page - Intial Masterplan*

7.1 Formal Considerations

The form of a built space, must be a result of the factors that surrounds it. The context. In an environment that is completely alien, devoid of life, and inhospitable, what would be the design drivers? In a world where there is no rain, no magnetic fields, no natural energy, using conventional design strategies will appear to be out of place. Nature on the other hand finds a way to evolve and continue to grow and shape the environment. Human beings similarly have come to evolve and grow, establishing our presence on every continent on Earth, in Space and even visiting even our natural satellite the Moon.

"Biomimicry [from the ancient Greek Bios – life and mimesis – imitation] is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies."[82] Digital construction techniques allows for biomimetic forms to be easily constructed. It is unknown what Martian biology is yet, or even if it exists. Using Earth's nature and its infinitely changing forms as a source of design inspiration will provide for an avenue for the exploration of an architectural proposition. A structure inspired by Earth's biology will also serve as a constant visual reminder, connecting the colonist to their home planet.

82 Biomimicry Institute ICal, "What Is Biomimicry? – Biomimicry Institute," accessed September 15, 2015. http://biomimicry.org/what-is-biomimicry/#.VfffhRGqqko.

Biomimicry offers the opportunity to study natural processes and mimic them on the planetary surface of Mars which is void of any known biological entities. Biomimicry also offers the ability to produce a dynamic architecture, ever changing, ever growing. No know terrestrial biological specimen would be able to survive in the carbon-dioxide rich environment of Mars. An architectural intervention that mimics biology and organics would also serve as a statement formally addressing the sentiment that the planet has been occupied by biological beings for the first time.

David Pearson in the introduction of his book *New Organic Architecture: The Breaking Wave* writes "No longer need the straight line, right angle, and cube be the dominate features. Using the "strength through shape principle", curved forms such as arches, vaults, domes, and spheres are stronger, more efficient, and more economical than the equivalent rectilinear structures."[83] The only orthogonal shapes that have ever left a mark on the planet, are the rovers that have visited the planet from Earth in the past three decades. However, as humans attempt to make their mark on the Red planet, more foreign 'straight line' shapes must not be added to the planet. Instead shapes that mimic and promote the rejuvenation of said planet must be adopted. Organic shapes.

83 Pearson, *New Organic Architecture: The Breaking Wave,* 8-9.

These shapes add more presence and stance in such an ambitious undertaking. Extremely sophisticated advanced technology and complex equipment will be utilised to full-fill this dream. Similarly the architecture of the place must also be an exemplar statement which promotes the advancements and complexity that architectural design software is capable of achieving at present. Exploration through mathematical relationships and computer algorithms have a real formal design presence given the context.

Given the harsh atmospheric conditions of the planet, life on the surface of the planet will be impossible without the use of space suits. Therefore, maximising built area with human friendly habitation must be a very important aspect of the formal qualities of the architecture. Again biomimicry gives a lot of clues as to what may drive the design qualities of the space. "Nature makes extremely economical use of materials, and this is normally achieved through evolved ingenuity of forms. Using folding, vaulting, ribs inflation and other measures, natural organisms have created effective forms that demonstrate astonishing efficiency. The many manifestations of this efficiency provide a rich source book of ideas for structures that could be radically more efficient than those found in conventional human-made architecture."[84] Domes offer the largest habitable volumes with the least amount of building material. A formal investigation of using hemispherical volumes to inform the design strategy will be adopted.

Materiality forms an integral part the architectural considerations of this project. Using the maximum amount of available resources on the site and effective use of Martian regolith to produce liveable spaces for humans will be explored. This approach offers subtlety to the context. Using the materials available would ensure that the architectural intervention will blend into the site and be part of it. "It was Frank Lloyd Wright who said that the relation of a building to its site is better expressed as "of the hill" rather than "on the hill". Ideally, an organic building will seem to grow out of the site and be unique to the site."[85]

84 Michael Pawlyn, *Biomimicry in Architecture*, (London: RIBA Publishing 2011), 9.

Anchored at the bottom of a large crater, the architectural intervention will be insignificant in scale. However, expressing subtly and restraint towards its surrounding will ensure that the intervention endures the test of time. For knowing 225 million kilometres away the rest of humanity is looking up at the tiny red dot in the sky and knowing that man has become an interplanetary species.

85 Pearson, *New Organic Architecture: The Breaking Wave,* 18.

7.2 Master Plan Design

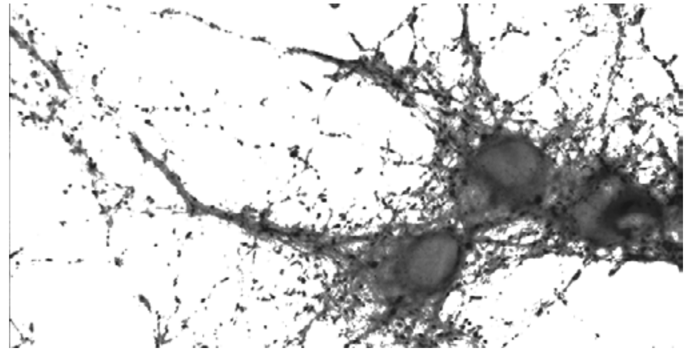
The main aim of the large scale master plan was to arrive at an organic growth model for the Martian colony. It is difficult and almost impossible to draw any similarities between any cultural, contextual, climatic or geographic conditions on Earth to inspire a method of creating a master plan. The new colony will start from scratch on a cold, alien desert landscape. The colony will have also have a varied make up of people of different cultural backgrounds.

A completely novel approach in design can be undertaken and this allows for some freedom towards design strategies. This freedom offers the exploration into the use of computational algorithms to aid in design and as stated section 2.2 one of this paper, one of the major aims of this research project. In order to do so, a number of pencil abstracted flow patterns were drawn and their nature analysed. By their very nature these images speak of a layered inter-connections on gradual paths. Although the images are constrained within a rectangular frame each of them appears to have endless possibility of growth.

"Organic architecture works with metamorphosis (the process of growth and change)…"[86] and as such one of the flow pattern images (Figure 71) was used to draw upon a series of interconnecting nodes. A hierarchical relationship is assigned to nodes which are over-laid on the flow pattern diagram. This connecting pattern provides for a template on which a master plan can be than derived using an algorithm (Appendix 11.2).

After the completion of the growth algorithm and subsequent drape, the resultant shape of the massing model arose as a series of interconnected curvilinear shapes that ebbed and flowed above and below the ground plane. Formally, the edge conditions of the massing model inform the perimeter of the habitable area and the overall shape of the built form. Shapes of curvilinear nature with semi-spherical volumes, are in tune with the organic and biological narrative of this research project.

86 Pearson, *New Organic Architecture: The Breaking Wave,* 10.



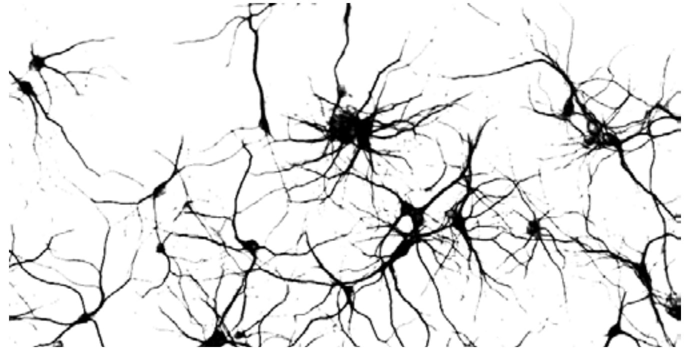
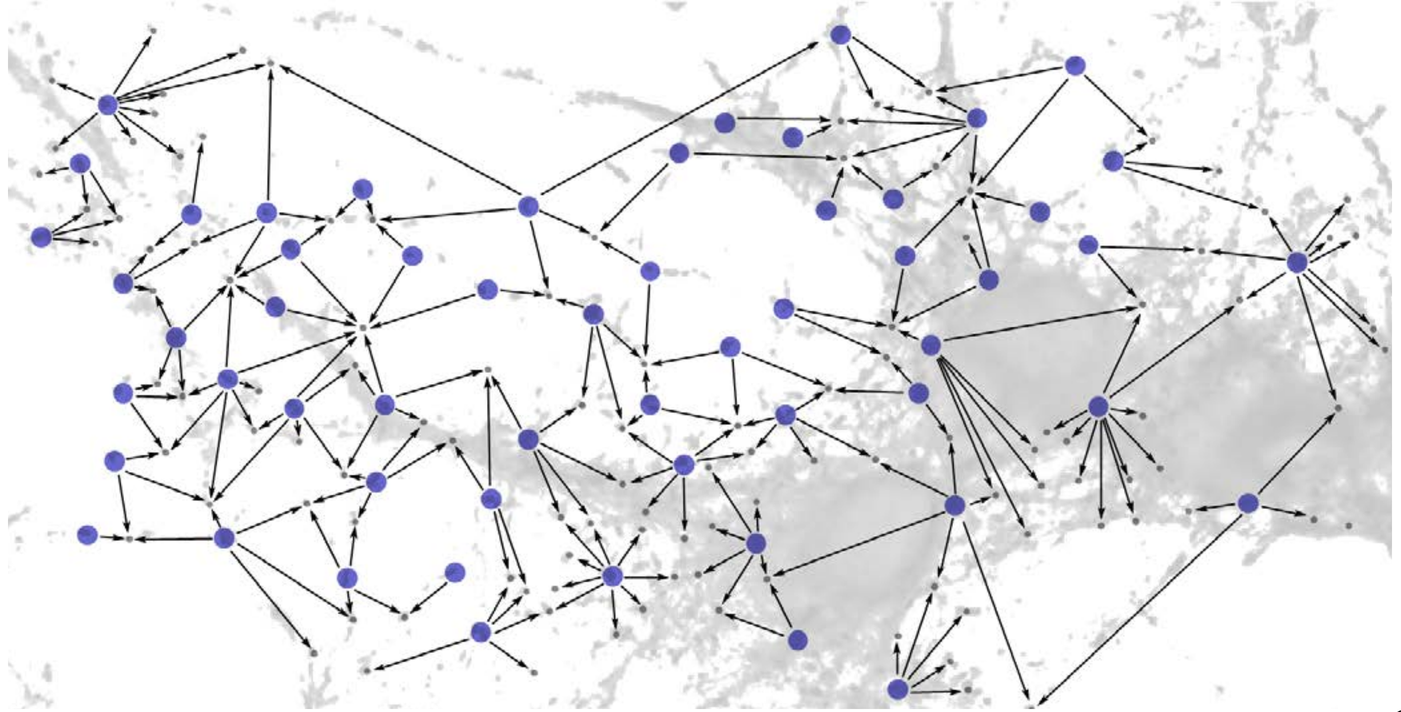


Figure 68 *Image left - Abstract flow pattern 1*
Figure 69 *Image left - Abstract flow pattern 2*
Figure 70 *Image left - Abstract flow pattern 3*

Figure 71 *Image below - Flow pattern for Masterplanning*



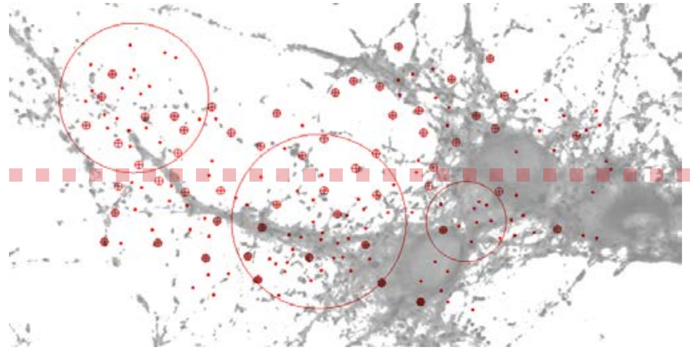


Figure 72 *Image above - First Layer - The series of nodes are imported into the program. Three areas of interest are identified.*

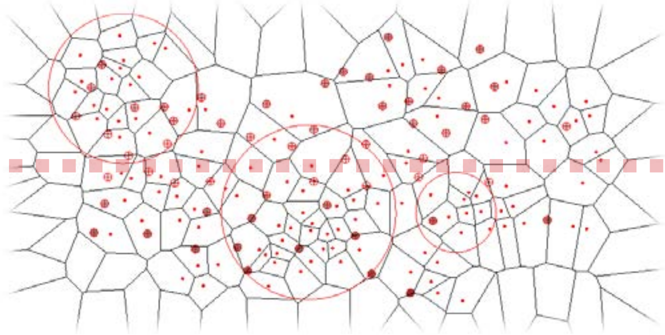


Figure 73 *Image above - Second Layer - The nodal structure is overlaid with a Voronoi cell structure, in order to determine constraints.*

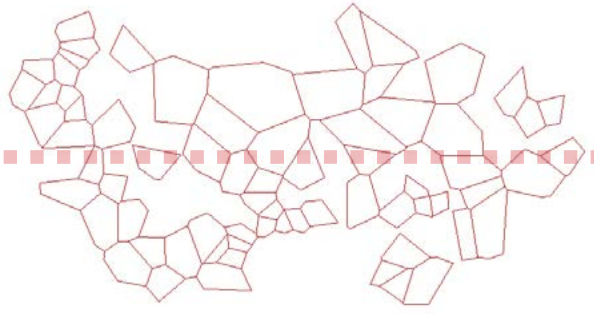


Figure 74 *Image above - Third Layer - A 40% to 60% cull is done in order to arrive at the correct ratio as determined in Section 6.1.*

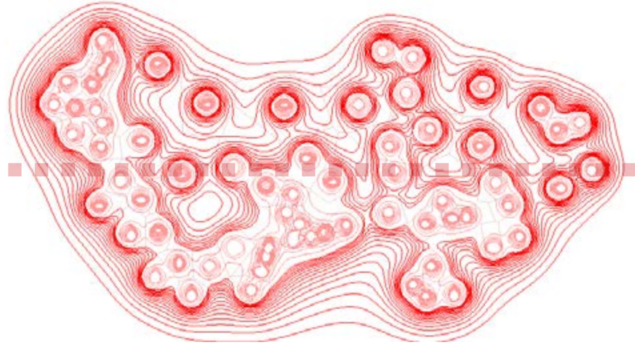


Figure 75 *Image above - Fourth Layer - The algorithm grows in plan from centre points of each of the cell structure. The growth stops once the required built area calculated in section 6.2 is achieved.*

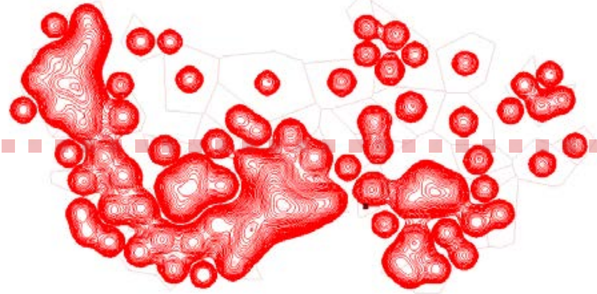


Figure 76 *Image above - Fifth Layer - The algorithm grows now grows in 3 dimensions to the extents calculated in Figure 67. This provides for a habitable volume for the new colony*

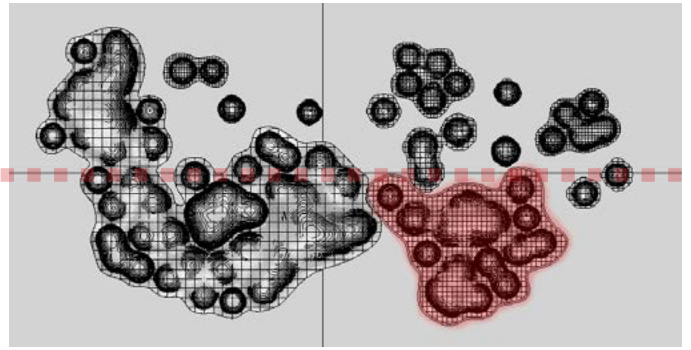


Figure 77 *Image above - Sixth Layer - After the growth algorithm is complete a drape over the volumes calculated is done. This completes the process which results in a complete volume being created for the habitation of 4500 people eventually. The area highlighted in red is the first area to be developed and the focus of detailed design of this research project.*

Figure 78 *Image below - Masterplan of colony in context*

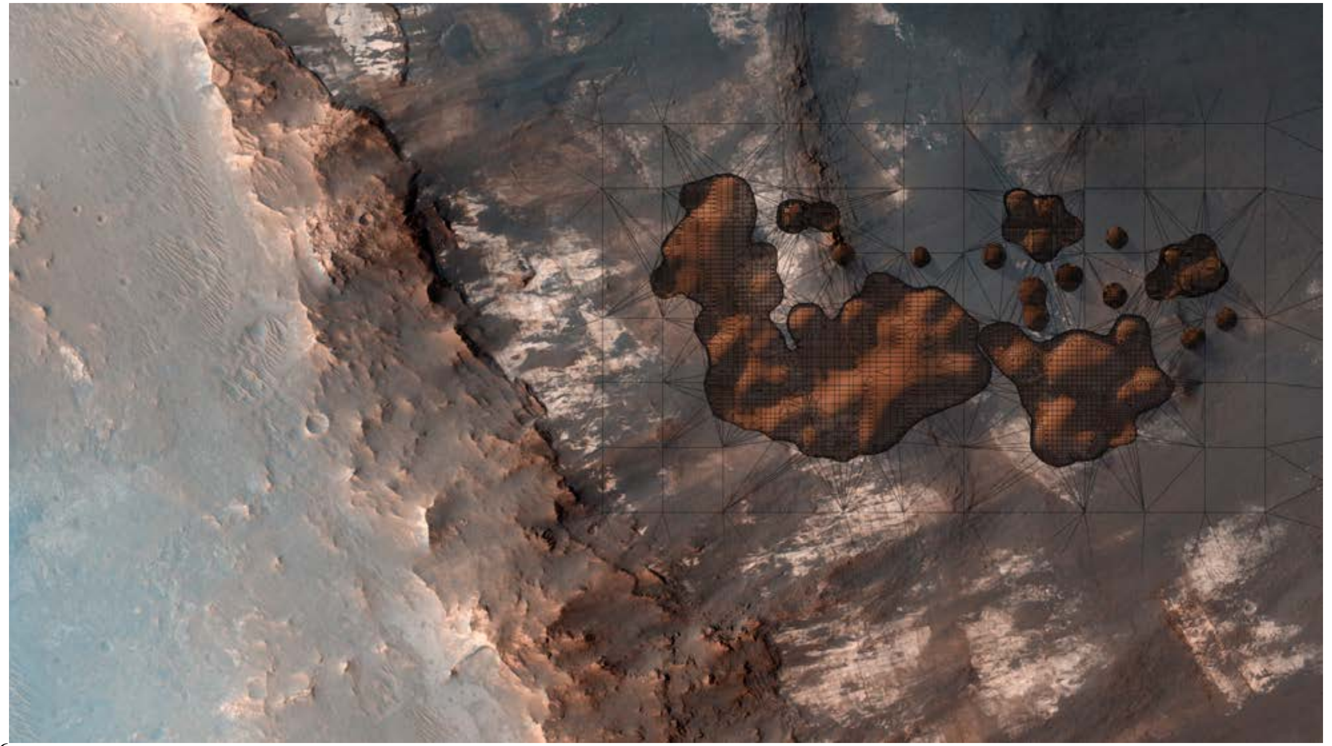


Figure 79 *Image next page - Aerial view of Master plan of colony in context*

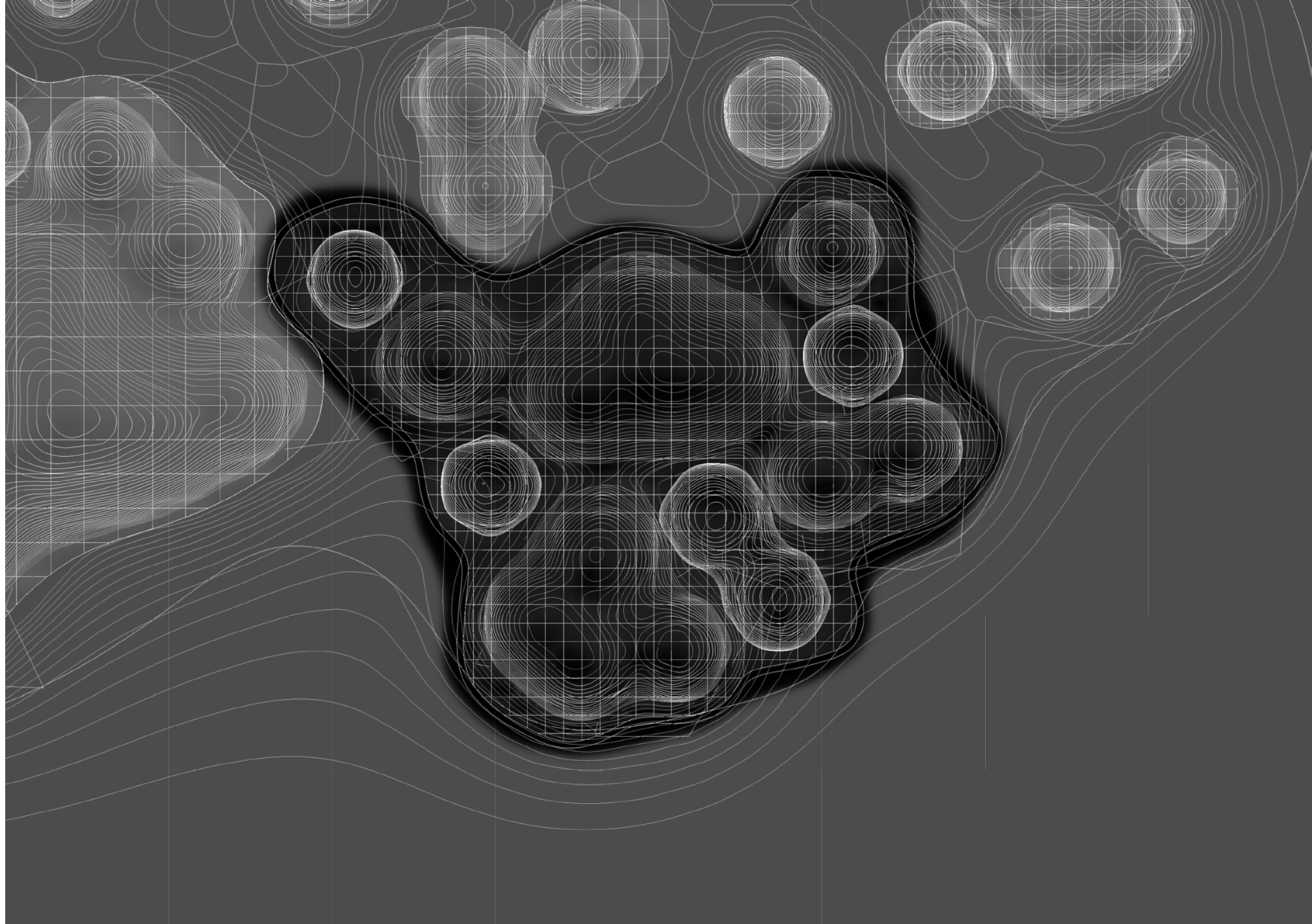


Figure 80 *Image next page - Massing plan of habitation to be designed in detail*

7.3 Material and Structure Considerations

It is completely unfeasible to expect transporting large amounts of construction material from Earth to Mars. At present cost estimates it costs about US $10,000 just to send one pound of weight into space. NASA has an active goal of reducing this cost hundreds of dollars within 25 years and tens of dollars within the next 40 years.[87]

A projection into 2076, would in that case mean that the transportation of large amounts of weight would be relatively less expensive than it is at the moment. However, weight is not the only issue that would be required to be taken under consideration in the establishment of new habitats. Volumes that can be launched into space are important factors to consider as well. Complete reliance on Earth made construction in that respect appears to be impractical.

In order to completely understand the different categories of Martian construction, the construction typologies that are available must be explored. Potential construction typologies can be split into three sections:

Type A: Pre-Built:

• Completely built on earth

• Fully assembled and tested before launch

• Delivered solution with immediate functionality.

• Volume and Mass limitations on launch dependent on launch vehicle.

• Interior fit outs completed on earth

Type B: Pre-Fabricated:

• Partially built – compacted and transported, assembled on site using some available resources

• Earth based testing will be required of important systems

• Assembly will be required, therefore functionality will some take time

• Volume maybe increased through exploration in pre-fabricated construction

• Interior fit outs would be done by crew or robotic equipment

Type C: In-Situ Construction

• Completely built using available resources on site

• Space constructed and tested

• Space construction would require significant time and crew to complete

• No restrictions in launch mass and volumes

• Interior fit outs would be done by crew or robotic equipment

The system of building used by this architectural proposition will be of Type B construction, similar to that proposed by Mars One. Construction will be based on large inflatable habitats that are transported by means of landers and erected at the pre-determined site in the Gale crater. Using this system of construction allows the reduction in both launch volume and mass. Interior division of spaces and other interior space must be then configured by the existing Mars One crew and/or robotic processes.

However, an inflatable design does not offer a complete solution to Martian architecture. Although a volume maybe created through this process it will not be entirely capable of protecting the inhabitants from solar radiation and large temperature variations.

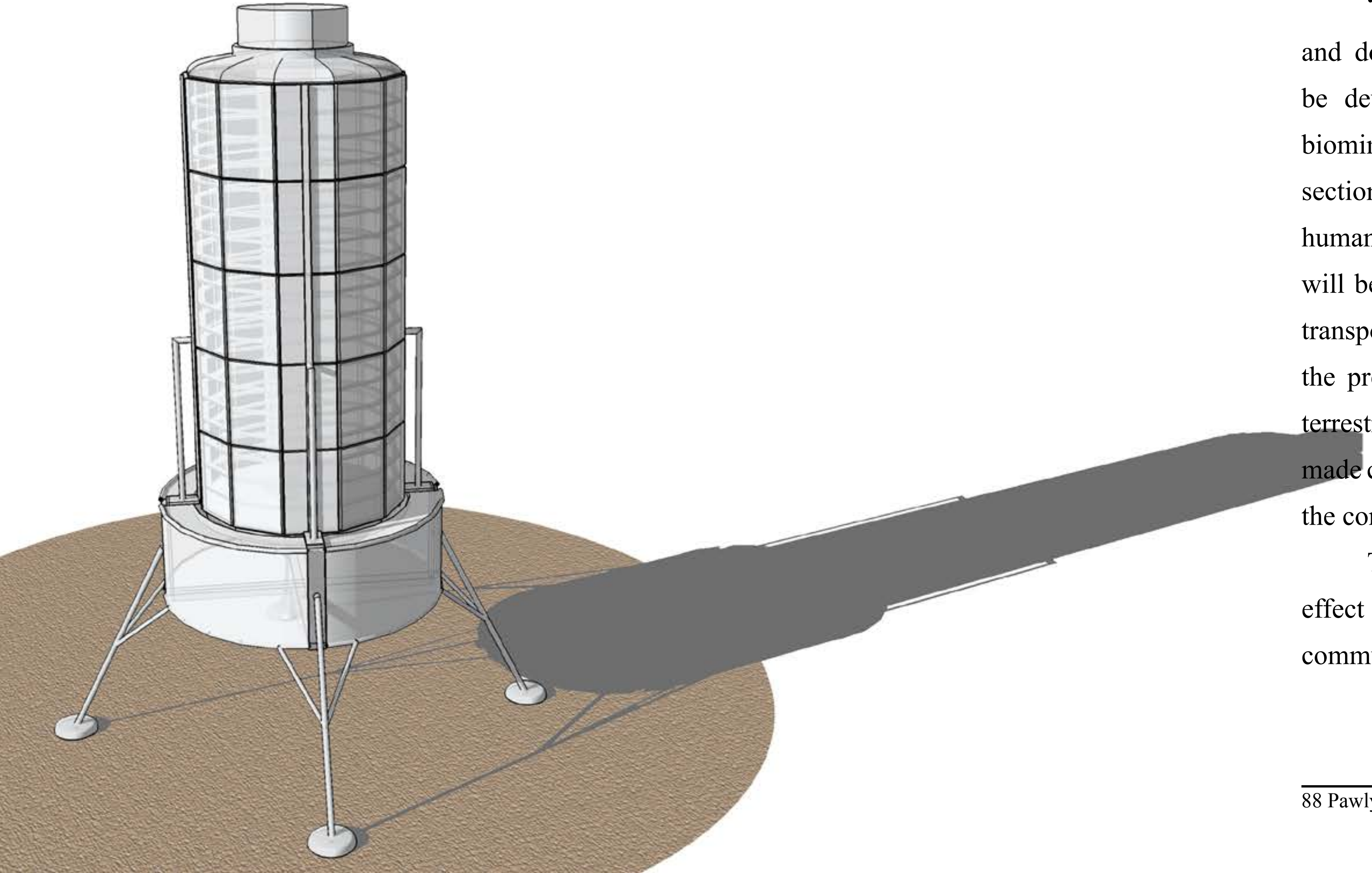
3D printing and exploration in the various means of construction through this process offers a wealth of possibilities in the creation of more rigid and safe structures. Inflatables designed from Earth will act as scaffold like structures as well providing the air tight finish that is required to ensure the habitation remains safe for human use.

The critical distinction between Mars One proposal and that of this research project is that of scale and design in which the Martian community of a hundred people live, work, and play will be discussed in the sections that follow.

87 Dunbar, Brian"Advanced Space Transportation Program: Paving the Highway to Space," accessed September 16, 2015. http://www.nasa.gov/centers/marshall/news/background/facts/astp.html.

Figure 81 *Image right - Lander on Rocket Fairing*

7.5 Lander and Inflatable Design



"Nature is and accomplished maker of shells and domes."[88]A system of habitable volumes will be developed inspired through its prevalence in biomimicry, organics and precedents studied in section 4.1.1 and 4.1.3. The model of occupying human friendly space on an alien planetary surface will be based on inflatable semi-spherical volumes, transported through landers from Earth. As with the precedents studied, current proposals of extra-terrestrial architecture involves a mixture of Earth made components and in-situ material use will realise the construction of the habitation.

This system will allow a fail proof and cost effect solution towards a realised living space for the community of 100 people by the year 2076.

88 Pawlyn, *Biomimicry in Architecture,* 16.

Figure 82 *Image right - Detailed Design of Lander*

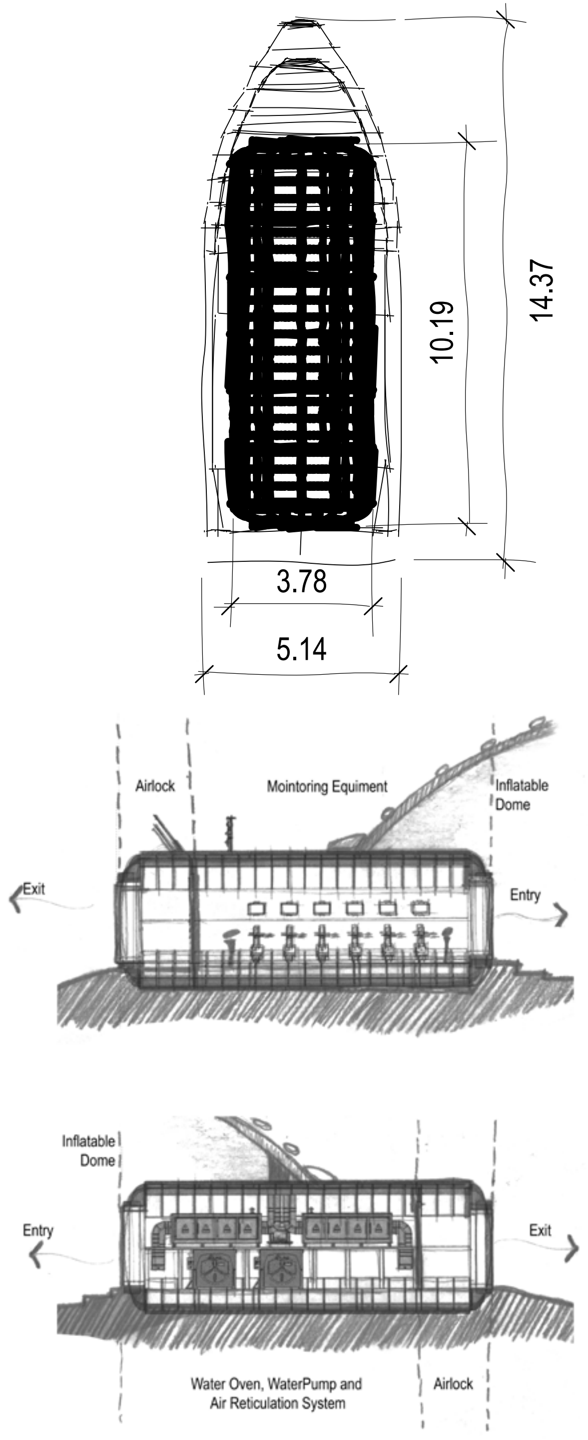
7.5.1 Lander Design

Current proposals of landing equipment to Mars (as those to be used by Mars One) are based on a rocket fairing diameter of 3.6 meters, using the Space X Falcon 9 v1.0 rocket and a modified Dragon Space craft. This allows only very small and confined landers being able to be transported to Mars. However, Space X is developing larger rockets for the use in deep space exploration. In particular the Falcon Heavy rockets.

The Falcon Heavy rockets are currently in research and design stage and are expected to begin testing in 2016 with missions shortly thereafter. [89] These rockets will be able to take significantly larger payloads, both in mass and in size into space and onwards to a trajectory towards Mars.

A large lander with a diameter of 3.8 meters and length of 10.20 meters, designed to house a large inflatable dome will be packed into it. The lander will also hold technical monitoring equipment as well the air revitalisation system. Landers will also act as air locks between the harsh Martian atmosphere and the more human friendly and controlled environment of the interior of the domes.

89 Svitak, Amy. "SpaceX Says Falcon 9 To Compete For EELV This Year." SpaceX Says Falcon 9 To Compete For EELV This Year. March 10, 2014. Accessed September 15, 2015. http://aviationweek.com/awin/spacex-says-falcon-9-compete-eelv-year.



7.5.2 Inflatable Design

Transparent inflatables membranes deployed through landers will form the habitable volumes for this architectural intervention. The inflatables will serve many purposes most important of which serving as a barrier between the harsh Martian environment and the occupants that inhabit the inflatables.

However, transparent inflatable modules on their own fail to protect people inside them as radiation will pass through and harm the occupants. Mars One and precedent studies in section 4.1 address these issues by burying the inflatable volumes under martian or lunar regolith, thus limiting and completely eliminating visual connection to the Martian land scape. A major design consideration of this project was to maintain a visual connection to the Martian landscape as discussed in section 2.8.

One way to mitigate the problems associated with solar radiation is the use of hydrogen gas as the gaseous element that fills the inflatable volume. However hydrogen gas is extremely flammable and may result in a dangerous situation.

Water, the liquid form of hydrogen serves as the best solution to the issue highlighted. A 300mm pocket of water will form a sufficient enough barrier to eliminate the issue of solar radiation.[90] Water will also act as an insulating agent and provide for a stable temperature on the interior of the inflatable habitat.

Water will also serve as a poetic metaphor serving as a "permanent psychological reminder of the main element of the mother planet – water constituting a sort of protective amniotic fluid for humans."[91]

90 "Fabulous Proposes 3D-printed Sfero Bubble House for Mars." September 11, 2015. Accessed September 16, 2015. http://www.dezeen.com/2015/09/11/fabulous-double-domed-3d-printed-sfero-bubble-house-mars-red-planet/.
91 Ibid

Figure 83 *Image right - Exploded View of Inflatable Domes*

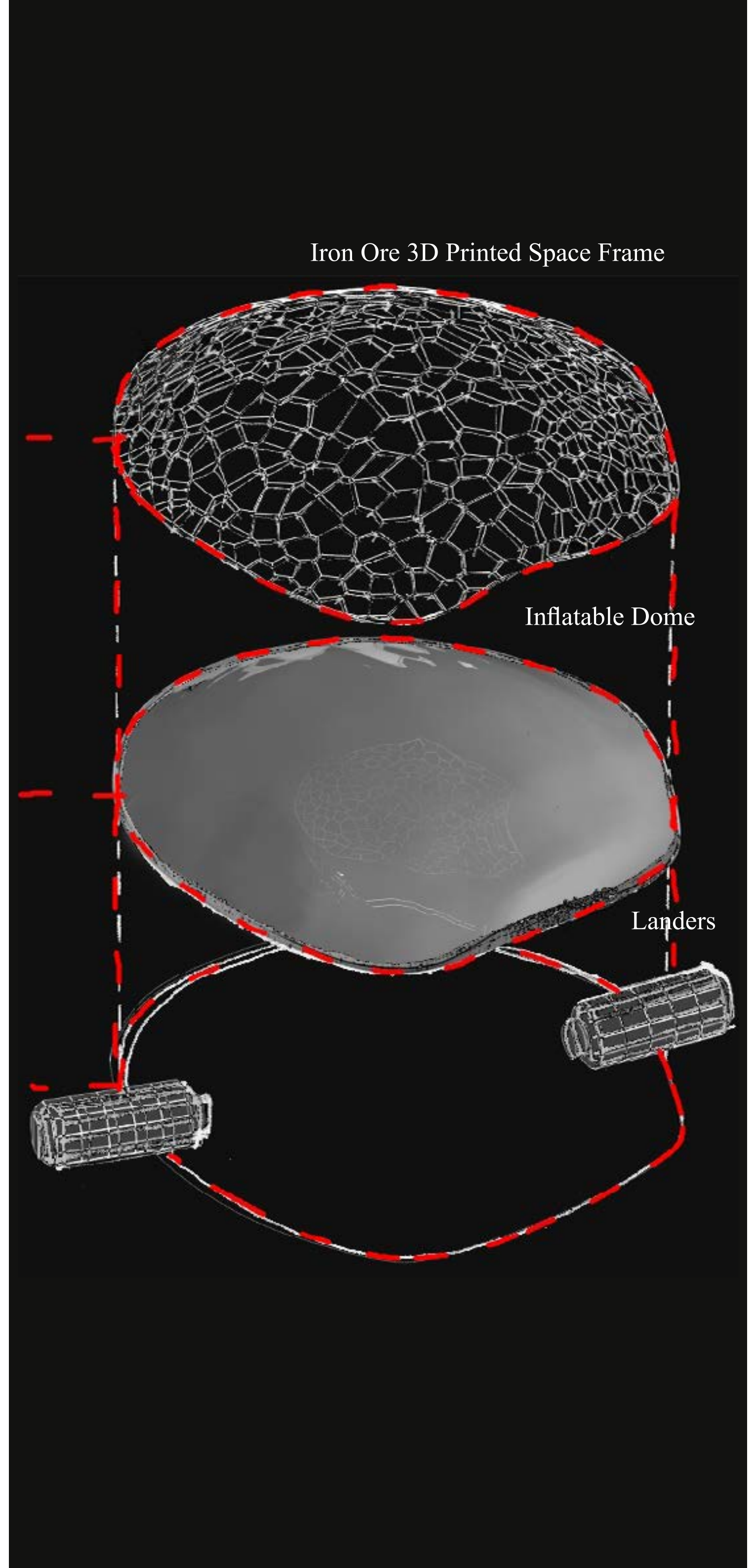
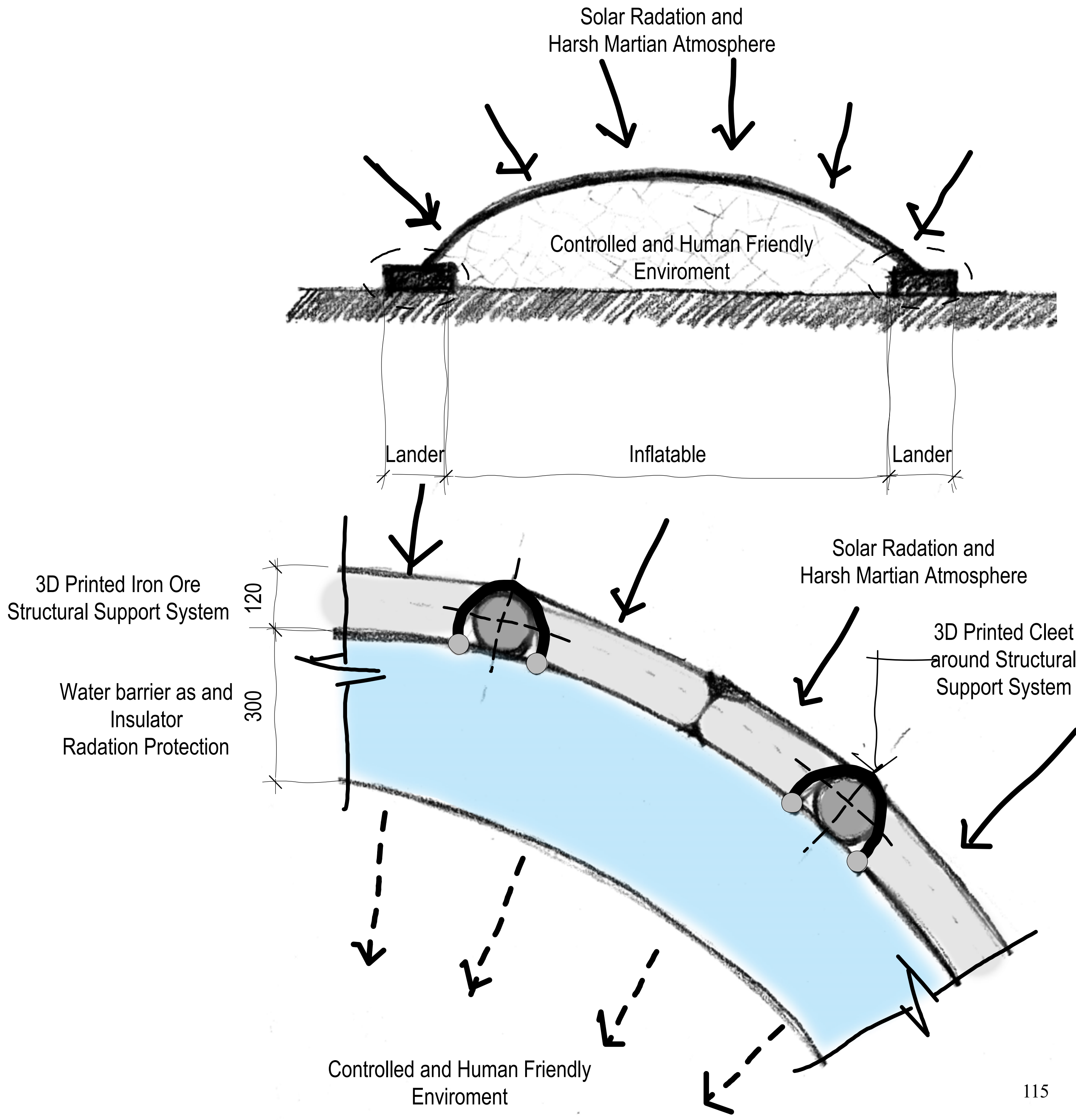


Figure 84 *Image right - Details of Inflatables*

Using water as a means of radiation protection, ensures that the habitats remain transparent and have visual connection to the landscape, furthermore, inhabitants will be able to enjoy a normal day and night cycle.

A water barrier structure would require significant structural support in order to support its own weight. This can be achieved by 3D printing an iron-ore space frame over the inflatable. As discussed in section 5.1.5, iron ore is abundant on the red planet and will be a useful building material. The inflatable is first filled with carbon-dioxide from the atmosphere to create its shape. Once inflated the 3D printing head attached on the gantry crane above can attach the space frame to the inflatable dome. Once complete, the carbon-dioxide filled pockets of the dome can be replaced with liquid water to create a permanent solution.



7.6 Form Exploration

Until now, design has been based on mass models developed through the algorithmic master planning technique. However, the architectural intervention requires a secondary structure above the water filled inflatable domes. This layer will offer protection to the domes from the high winds that are prevalent on Mars. Furthermore, the structure will act as a grounding tether that secures the inflatables to the Martian surface. Maintaining visual connection between the Martian landscape and allowing safe natural light to penetrate the habitation was a major architectural consideration of this project. Two issues that Mars One and precedent studies in section 4.1 fail to address. Using water as discussed in the previous chapter ensures these two considerations are met. The third layer of protection must also be sympathetic to these issues. Bearing this in mind forms that permit these considerations were explored.

Construction using digital mediums and exploring biological forms is the corner stone of this research, therefore it seemed appropriate to explore digital form making inspired from biomimicry.

The initial forms where explored using a geometric subdivision. Figure 85 describes this subdivision done in a linear X – Y direction. This first iteration lacked an aesthetic quality that represented a biological nature. Figure 86 was the second attempt at from generation. This time the subdivision was done in the X – Y direction with a 45 degree angle alteration. The second iteration, again failed to produce a biological aesthetic quality.

After the initial failed attempts, research into a biological patterns was done. After analysing numerous images of biological entities, a close up image of a leaf pattern was chosen to analyse further (Figure 867. The image was overlaid with points and lines drawn over to create a network of shapes. This resulted in a Voronoi pattern being drawn.

A Voronoi pattern is mathematical relationship, which is prevalent in nature and biology.[92] It is drawn by creating points and connecting them to the nearest point and then bisecting each of the lines with a perpendicular line. This diagram and the resultant mathematical relationships it creates, provides the ideal form generation technique. An algorithm was created (Appendix 11.2) by which the Voronoi pattern was overlaid on the massing model created in

92 Future Concepts in Architecture, "Voronoi Diagrams: Nature and Archtiecture," last modified May 7th, 2011, https://neoarchbeta.wordpress.com/tag/voronoi-diagrams/

Figure 85 *Images right - First iteration XY subdivison*

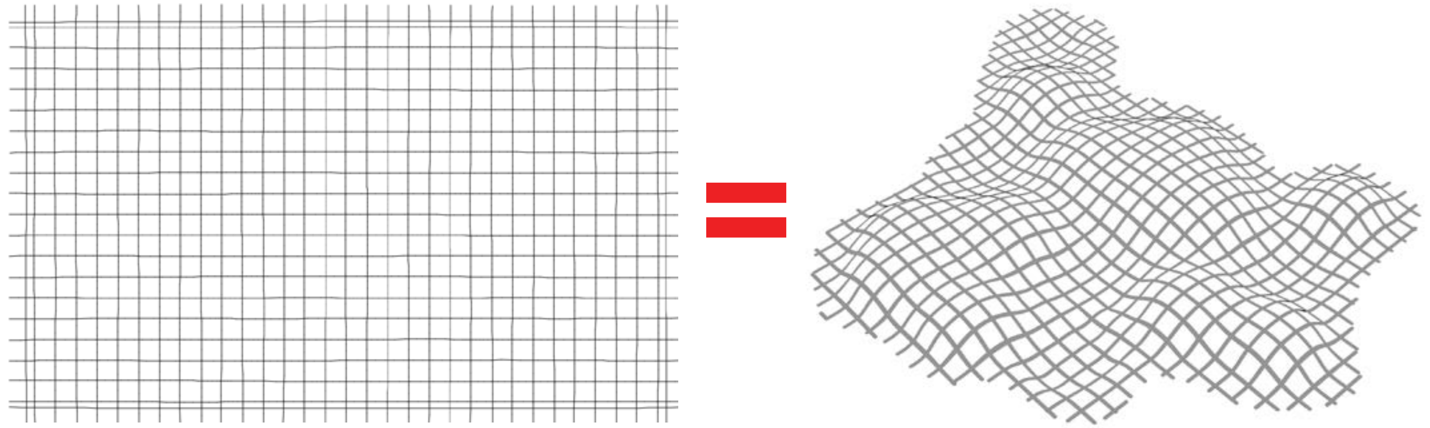


Figure 86 *Images right - Second iteration 45 degree XY divison*

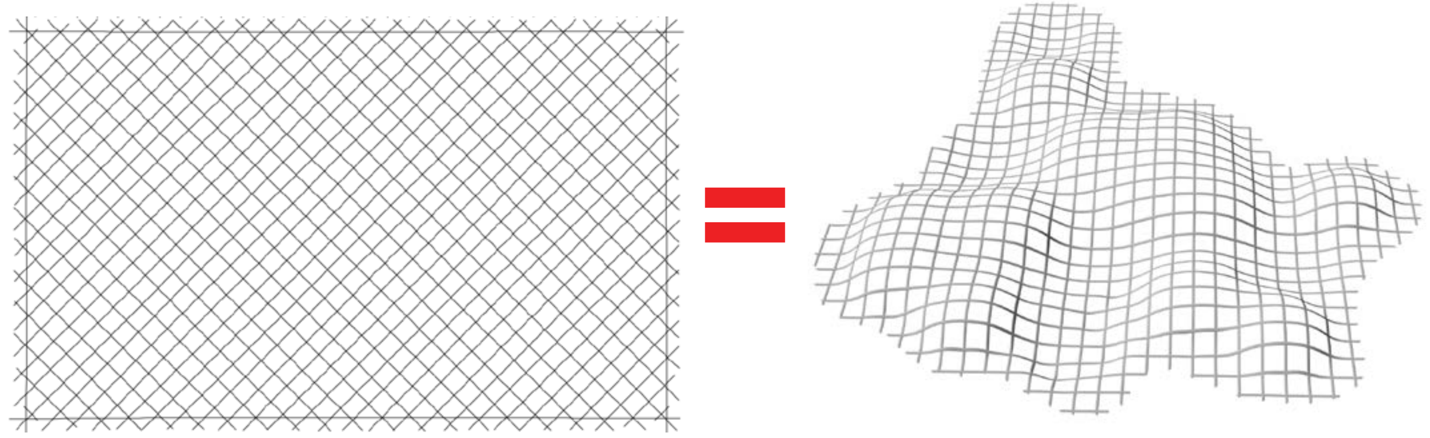
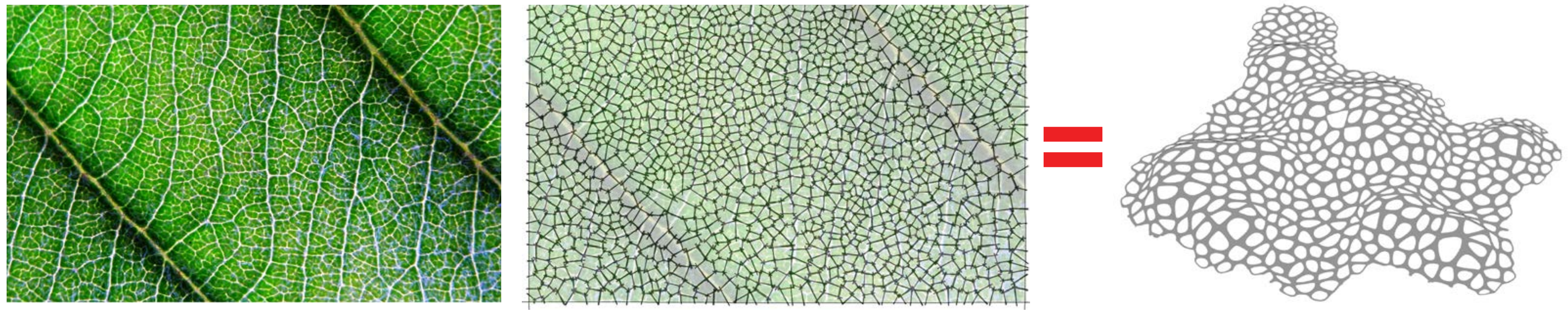


Figure 87 *Images below third and final iteration derived from Voronoi subdivision*



the master plan design stage. Figure 87 was chosen as the final form, given the iteration most reflected an organic and digital aesthetic.

This protective layer is conceived as a 3D printed shell. 3D printing in the conventional sense on Earth is done through a process of melting plastic filaments into a usable object. This process is a very precise and efficient means of construction. This offers a world of opportunities in creating large volumes and spaces that can be all created remotely and quickly. However, conventional 3D printing has a fundamental flaw in that it would require extremely large amount of precursor material to be able to print structures large enough.

Similar to the precedence study at section 4.3.2 using an inorganic binder mixed with the Martian regolith could provide for a means of construction that would require less raw material being needed. However, this system would still require the inorganic binder to be transported from Earth or created or mined/from non-terrestrial surfaces.[93]

Researchers recently made headways into laser sintering 3D printers. This system of 3D printing works by laying down layers of material that sintered (melted and hardened) by heat lasers. As with the regular 3D printing a feeder material will be required. In this case instead of plastic or Martian regolith mixed with in-organic binder, Martian basalt is melted down and used as the construction material.[94][95] The resultant product is a very high strength material and when compared to residential concrete.[96]Further testing into this process has resulted in the creation of unsupported spans, including cones, hemispherical domes, and ogive domes.[97] The protective shell would be realised through this process of construction.

93 Eddie Krassenstein, "NASA Tests Feasibility of 3D Printing on the Moon & Other Planets Using In-situ Materials and a Really Hot Laser," accessed August 15th 2015, http://3dprint.com/30302/3d-printing-on-moon-mars/
94 Ibid
95 Basalt is abundant on Mars as highlighted in section 5.1.7 and in precedent study 4.1.2.
96 Eddie Krassenstein, "NASA Tests Feasibility of 3D Printing on the Moon & Other Planets Using In-situ Materials and a Really Hot Laser," accessed August 15th 2015, http://3dprint.com/30302/3d-printing-on-moon-mars/
97 Ibid

Figure 88 *3D printing technique*

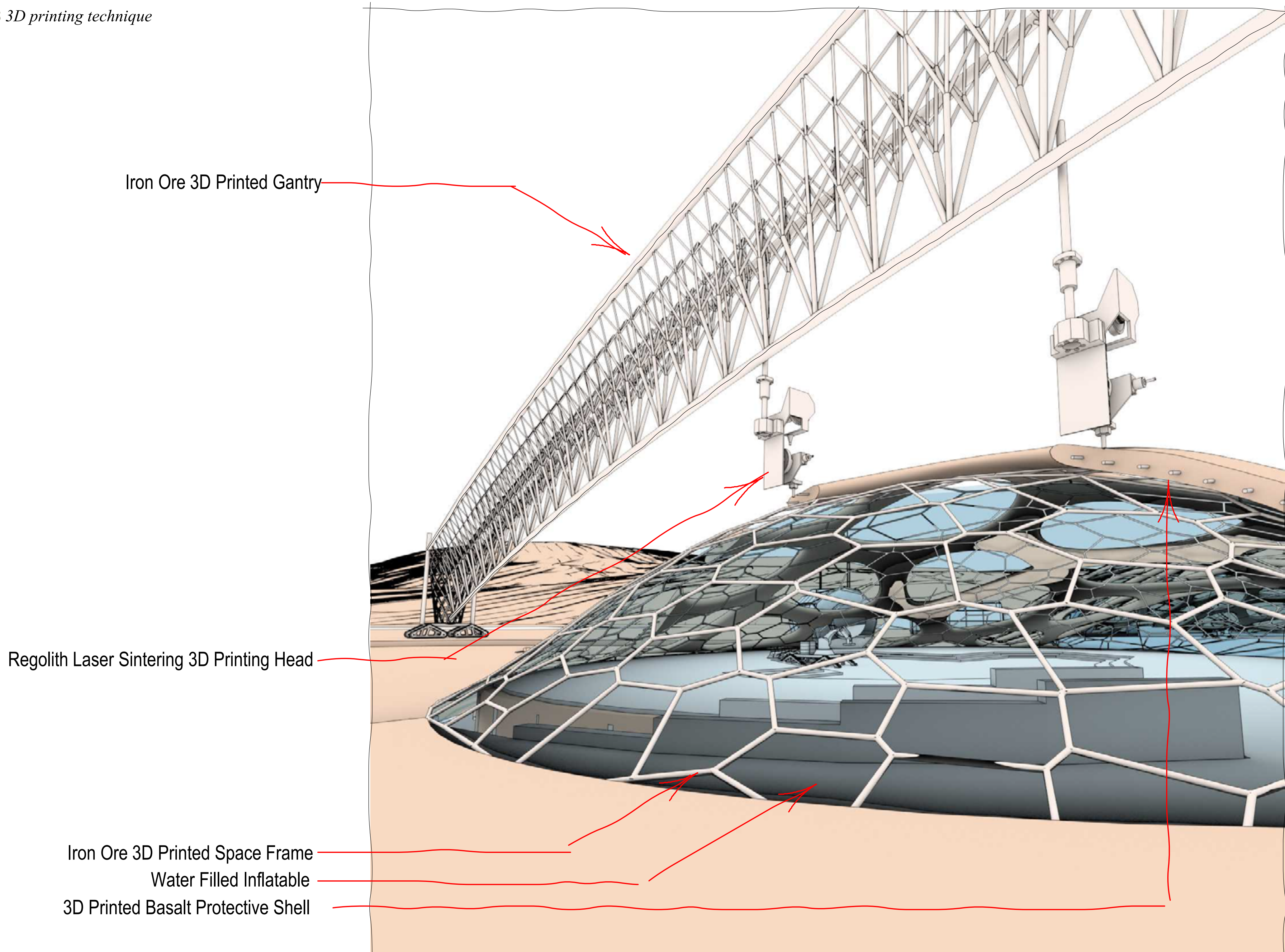


Figure 89 *Image next page - Intial Complete Habitat Plan*

7.7 Intial Design

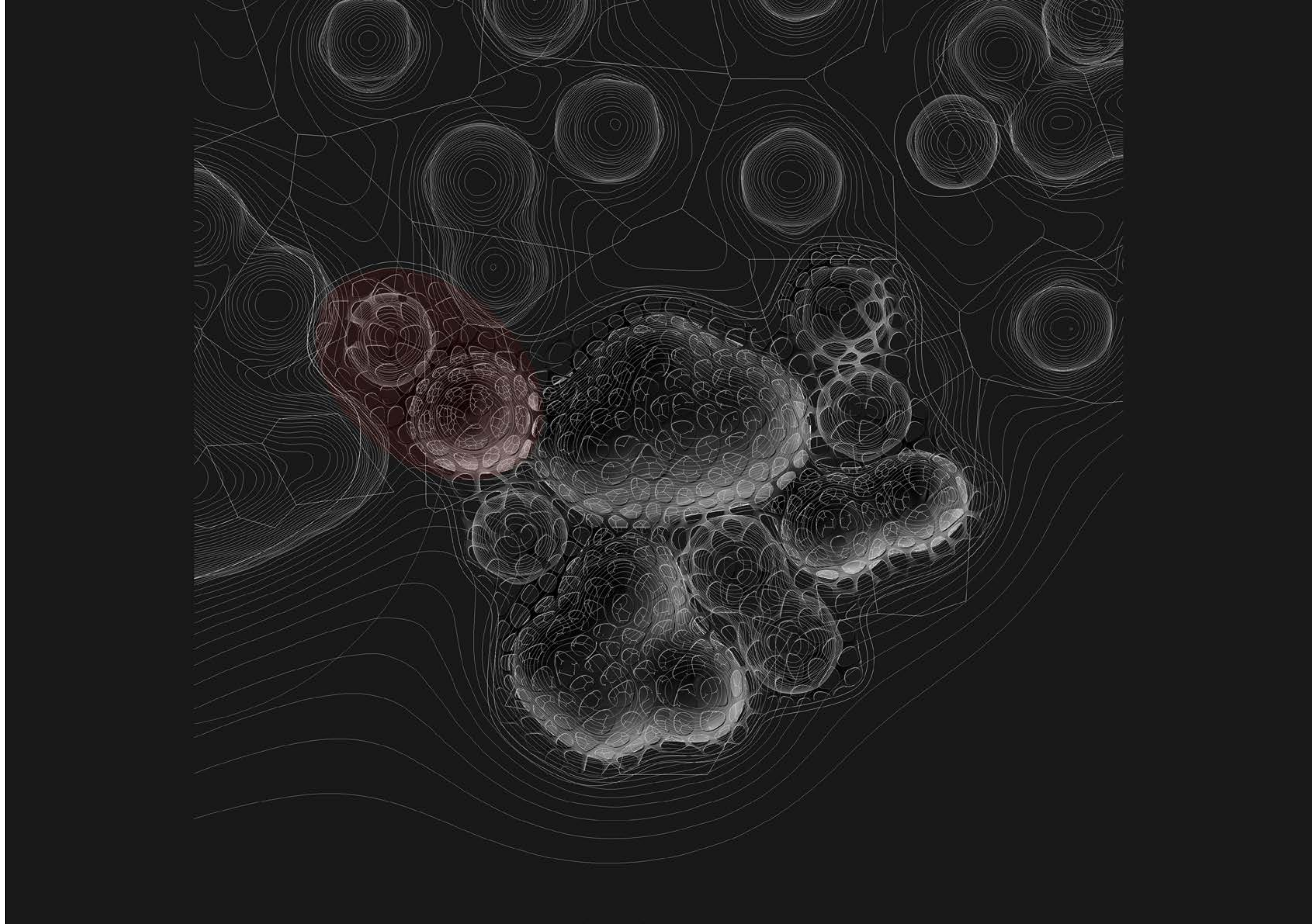


Figure 90 *Image right - Intial ground level plan*

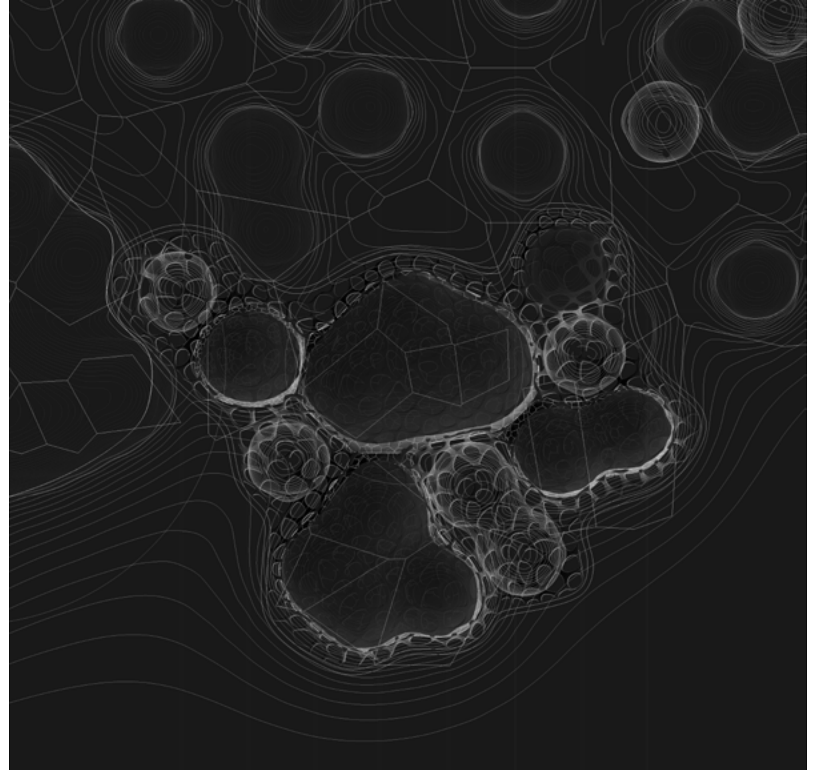
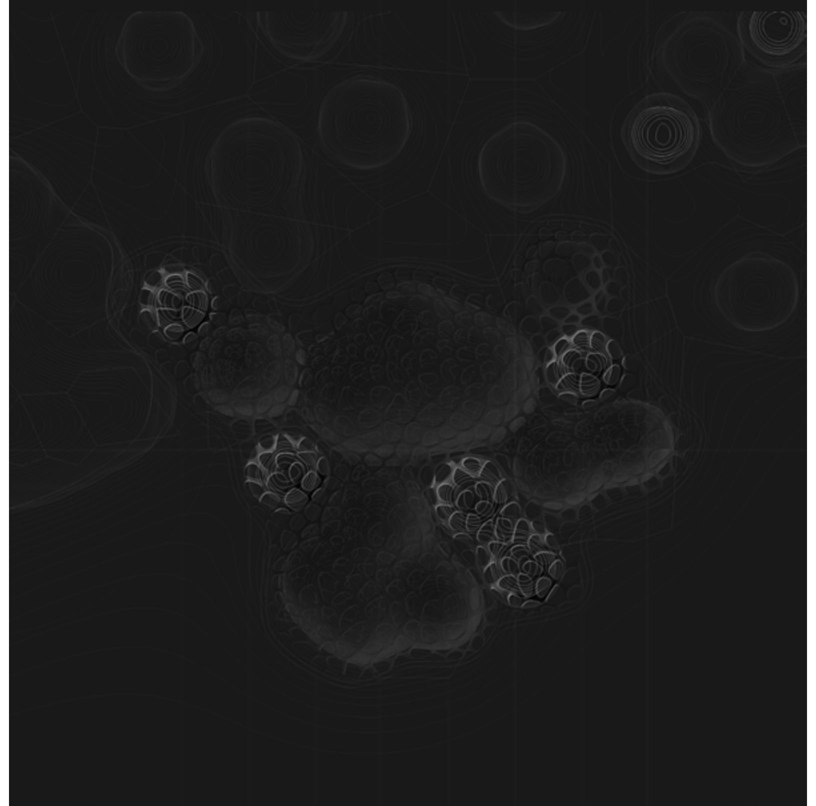


Figure 91 *Image right - Inital subterranean level plan*



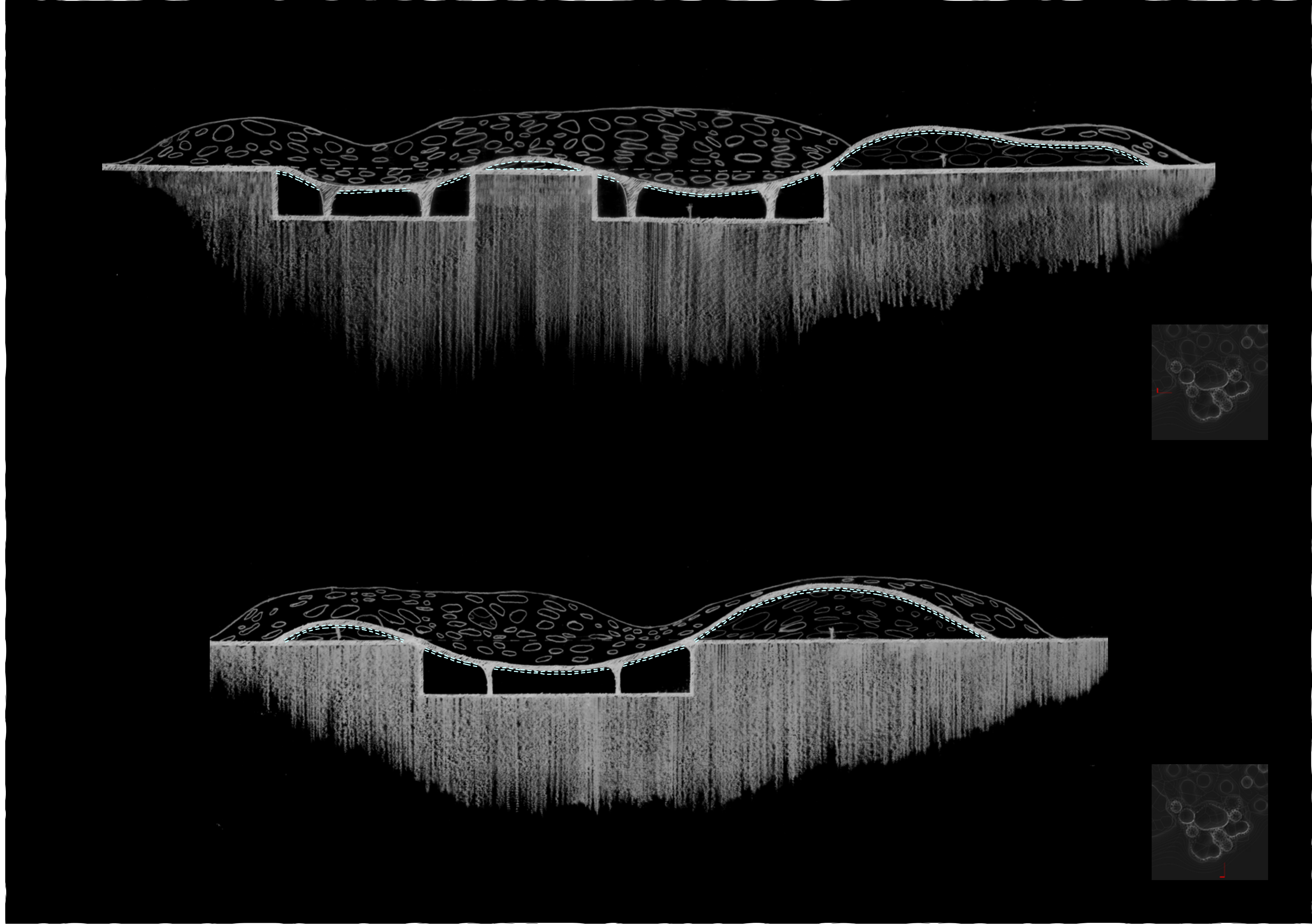
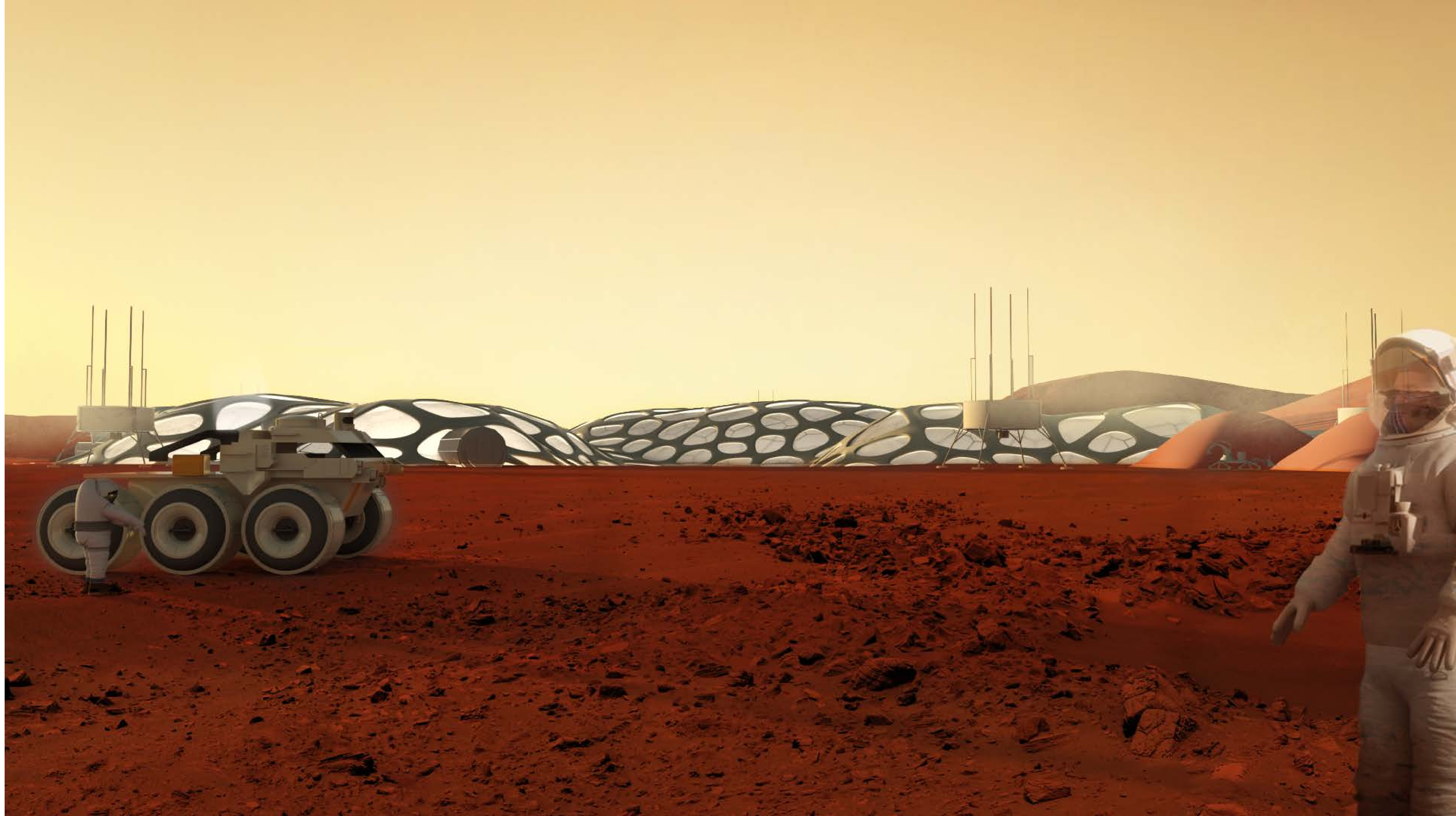


Figure 93 *Images previous page - Initial sections of habitat*

Figure 92 *Image right - Human perspetive view of first habitation in context*



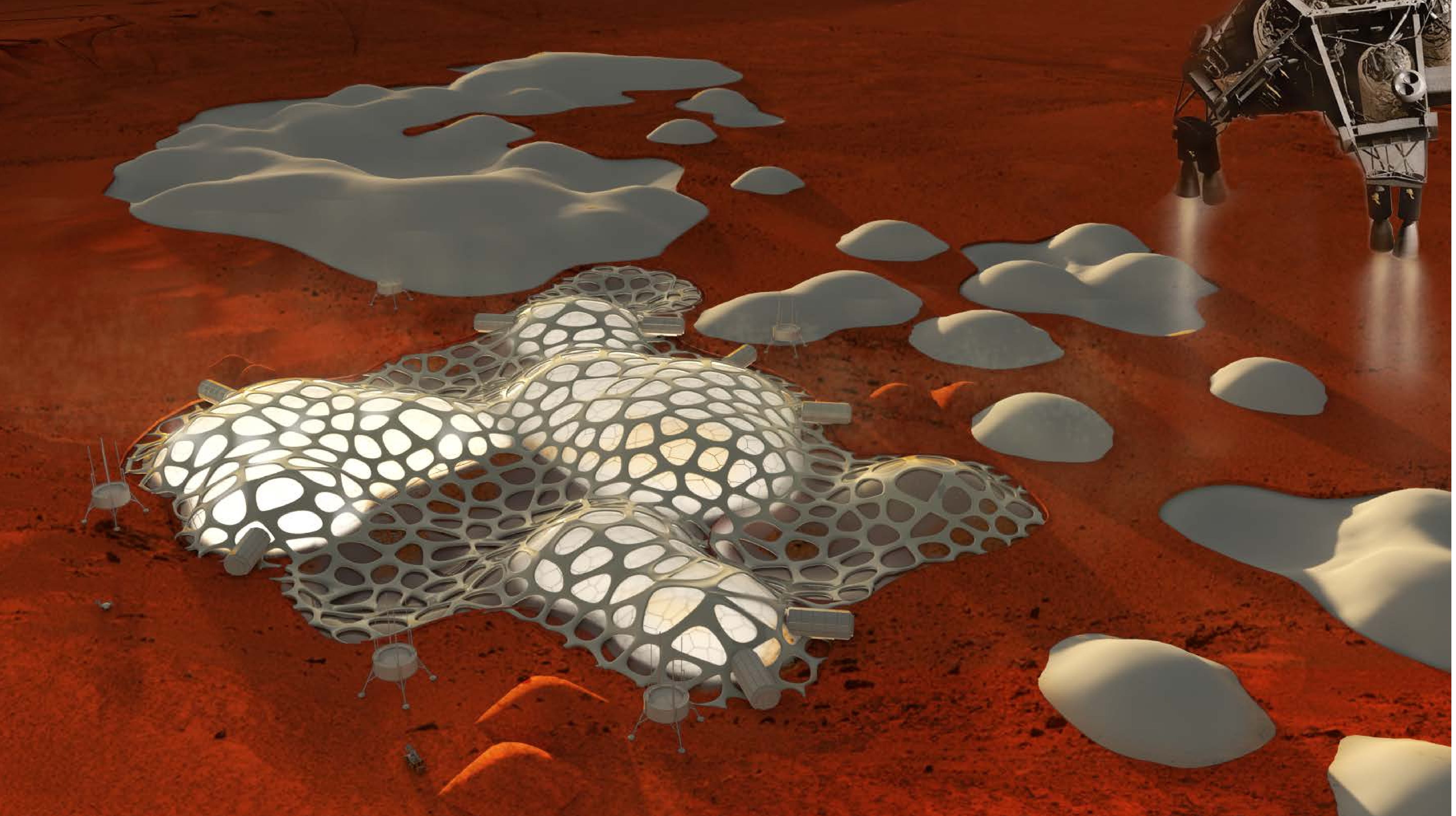


Figure 94 *Image left - Aerial view of first habitation in context*

7.7.1 Sequencing of Construction

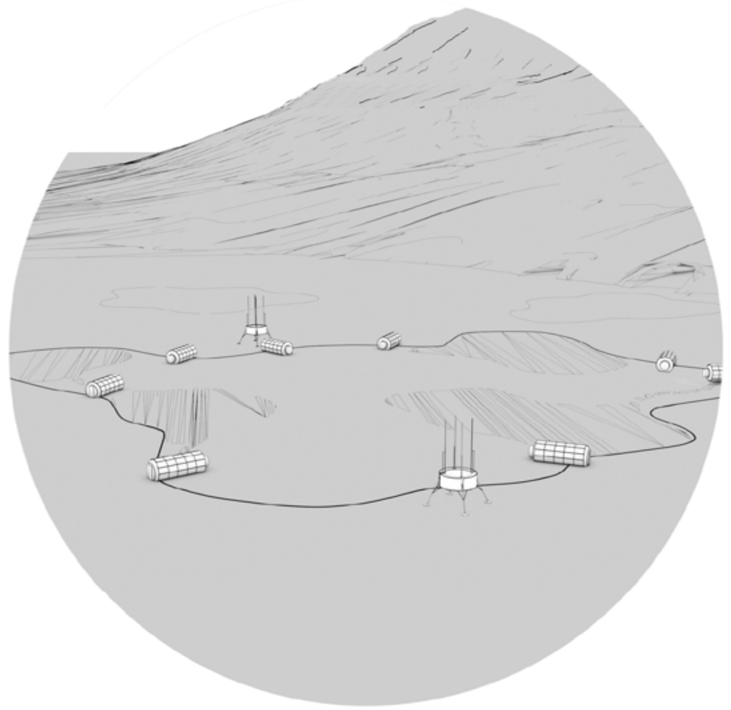


Figure 95 *Image above - location in the Gale Crater is depoisted with landers and areas required to be excavted mapped*

Figure 96 *Image above - Excavation completes. Preparation of 3D printed mobile crane occurs.*

Figure 97 *Image above - 3D printed crane is complete, habitation modules are ready to be constructed.*

Figure 98 *Image above - Iron ore space frame is printed and inflatable modules are deployed to created habitable volumes.*

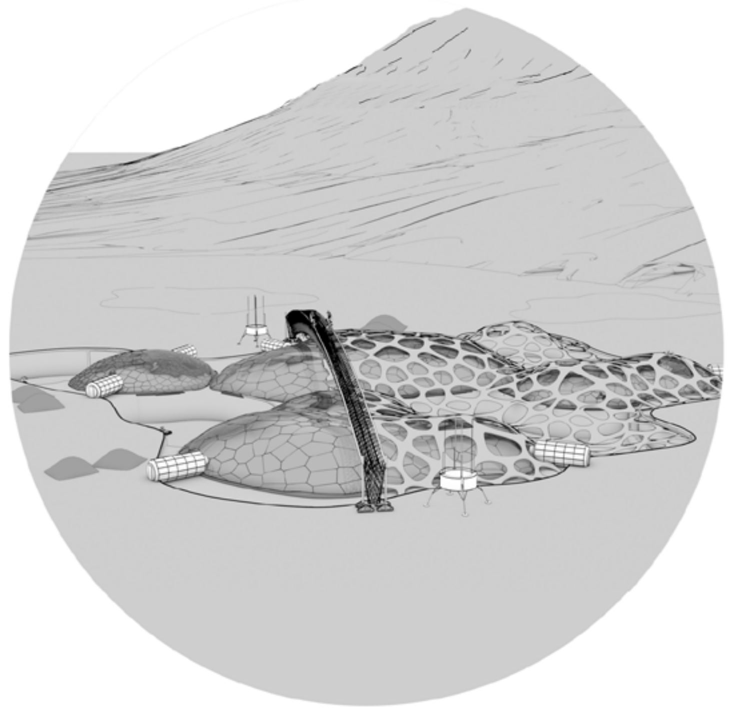


Figure 99 *Image above - protective 3D printed laser sintered regolith layer.*

7.7.2 Internal Division of Spaces

Upon completion of the form finding process, the interior planning process can now begin. One of the fundamental issues that govern the design of this whole project is the use of available resources, using the "hill" and "being part of the hill" a vernacular architecture.

The precedent study at section 4.2.1 offered an appropriate yardstick to aid in the process of internal division. It also offered the possibility to explore design through the use of central courtyards as circulation space, communal living space and secondary food growing areas. Matmata was analysed and studied to offer the prospect of creating living/occupiable spaces for the Martian colonists.

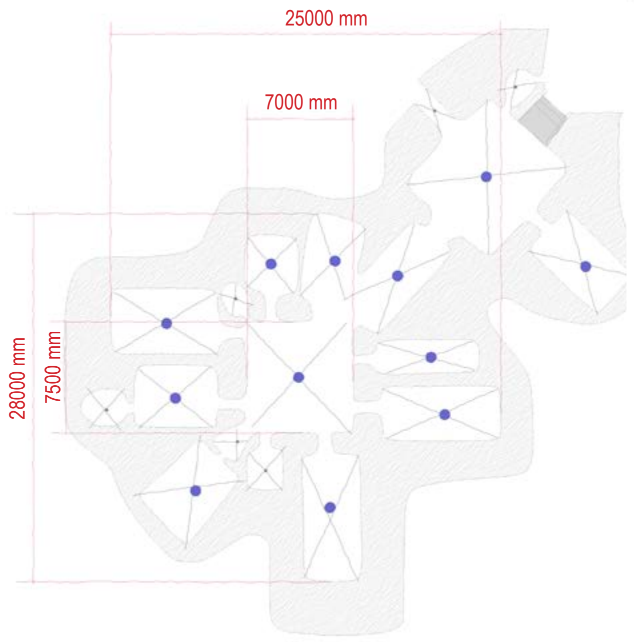


Figure 100 *Image above - First Layer - Centres of each spaces are identified.*

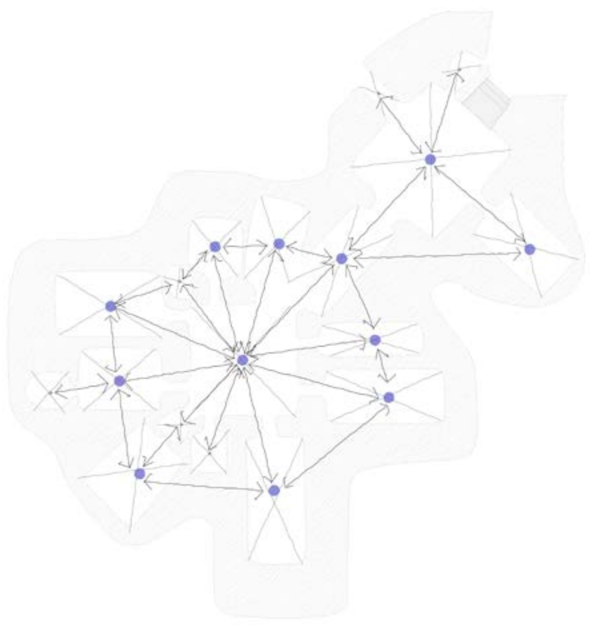


Figure 101 *Image above - Second Layer - Attractions between spaces are identified and their relationships are studied.*

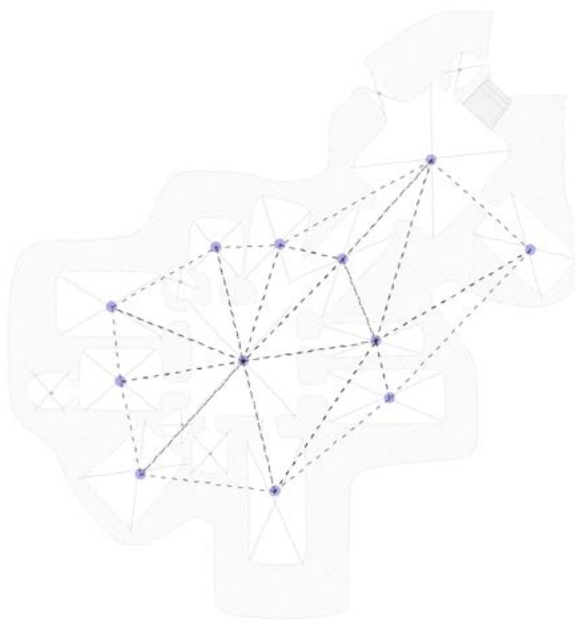


Figure 102 *Image above - Third Layer - Centres are joined to create a pattern.*

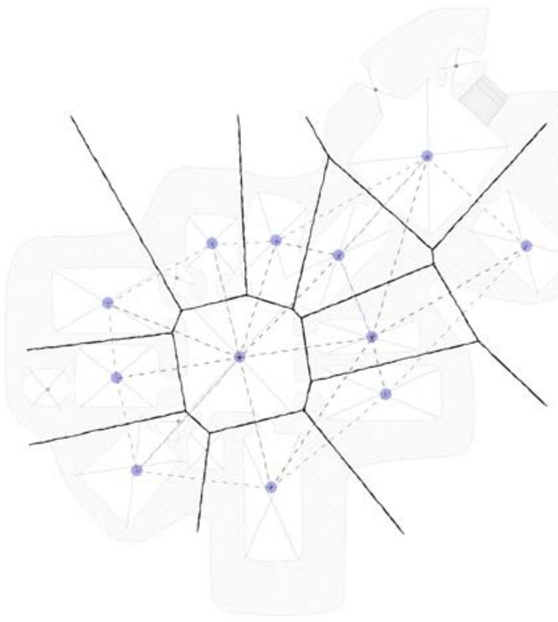


Figure 103 *Image above - Fourth Layer - Centre points are used to create a Voronoi cell structure.*

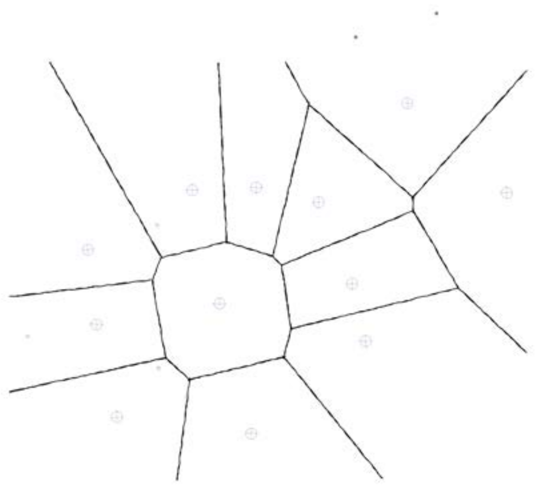


Figure 104 *Image above - Final Layer - The final Voronoi cell structure used as principal space division tool.*

7.7.3 Inital Planning

Based on the Voronoi pattern double height volumes were created. A small area of the complete habitation was designed as a prototype. The volumes created functional useable space for occupants. These spaces would provide for the living modules for the initial 100 in habitats. Furthermore, the volumes can then be allocated according to the requirements of the brief set out earlier.

An analysis of the internal division was consequently done to measure the successes and failures the design achieves. Based on the success of the design a similar strategy can then be applied to the entire habitation.

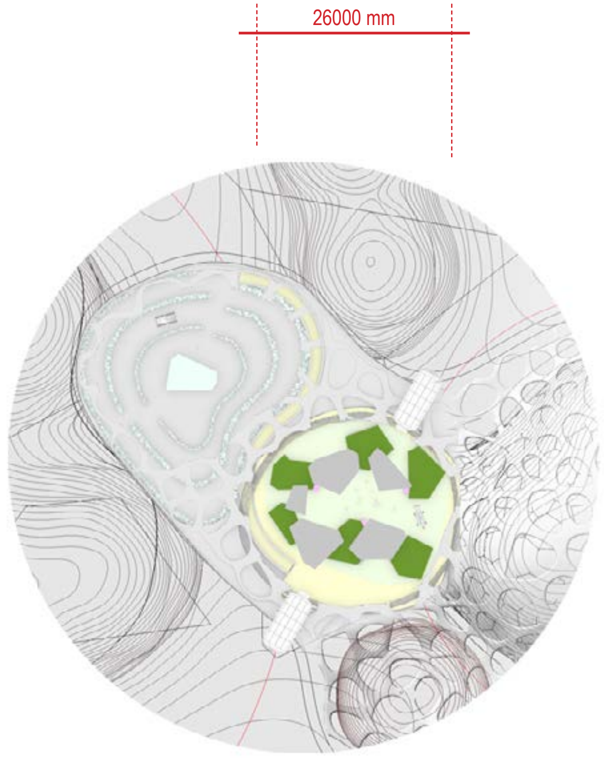


Figure 105 *Image above - food growing areas and living modules.*

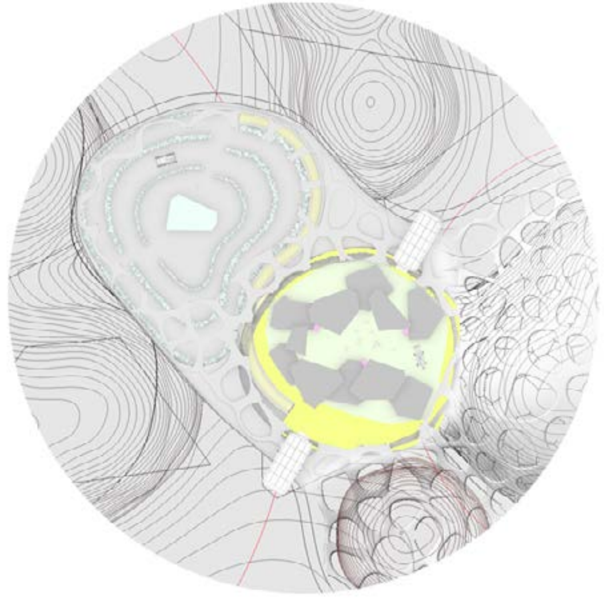


Figure 106 *Image above - Secondary Circulation.*

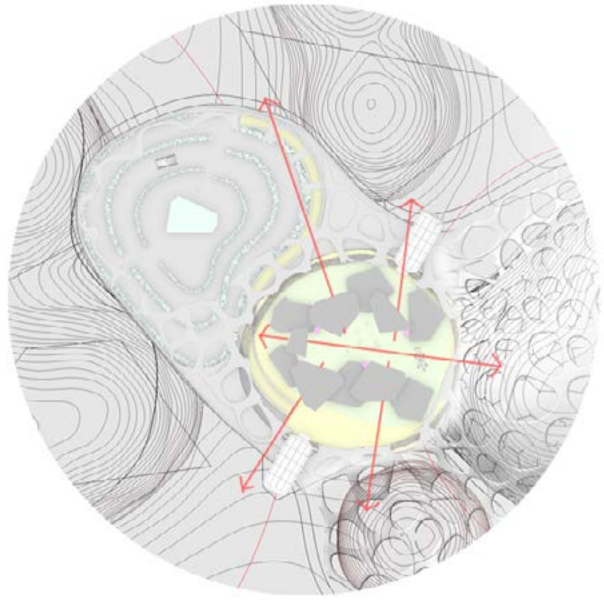


Figure 107 *Image above - Physical and Visual connection from internal courtyard.*

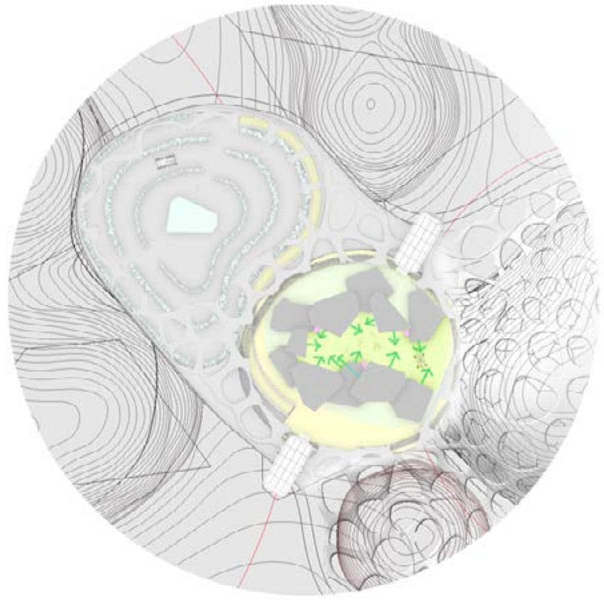


Figure 108 *Image above - Visual connection to internal courtyard.*

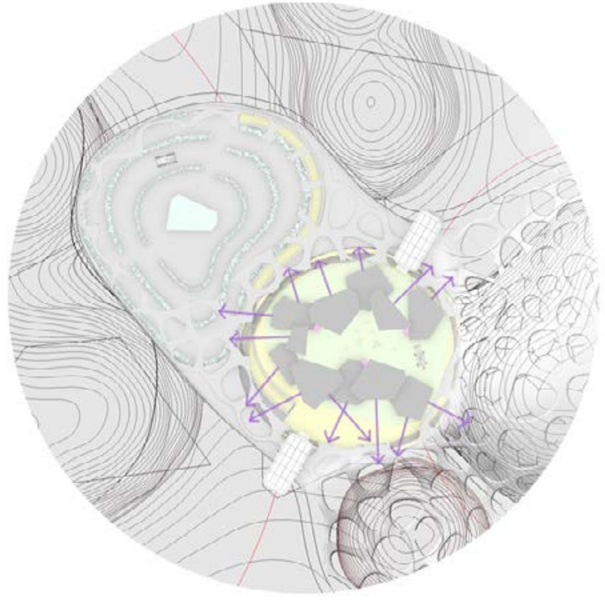


Figure 109 *Image above - Visual connection to the Martian landscape from living modules.*

Figure 110 *Image left - Initial render of courtyard*

Figure 111 *Image right - Initial render of food growing subterranean area*

7.7.4 Inital Planning - Outcomes

The initial planning resulted in a number of successful design outcomes. One of the major aims of this research was to ensure that occupants would be able to maintain a degree of visual connection between the Martian landscape and themselves. The use of a transparent barrier maintains this visual connection and also allows the interior to be filled with natural daylight, something Mars One's proposal fails to address. Creating a double height volume helps to create a three dimensional permeable space which goes beyond the standardisation that Paul Zucker refers to in chapter 3.2.

Initial planning of the interior also resulted in a number of issues that requires further addressing. Initial spatial division was conceived as 3D printed modules. However, as highlighted in section 7.5 this is not practical. Zubrin in his book *The Case for Mars the Plan to Settle the Red Planet and why we Must,* suggests using bricks as the initial material of choice for the creation of structures.[98] Using this material as the spatial division tool, stays in tune with the vernacular narrative of this project. Furthermore, using bricks allows robotic machinery to place them. This intern reduces human involvement in the construction process.

Matmata offered possibilities of using the central space as a tool for circulation and communal living space. The initial plan failed in creating a clear central space and the connections between the living modules, were not clear. Creating a more pronounced communal living space would allow a sufficient gradient of public to private space to ensure that the colonist all have their own personal space.

Christopher Alexander in his book, *A Pattern Language* writes that the internal divisions of spaces should be arranged in a sequence which reflect their degrees of privacy.[99] Using a Private – Semi- Private – Semi – Public and Public configuration in spatial design could achieve this gradient.

The initial plan also lacked clear clusters and the centrality that is evident in the Matmata case study. This idea is further reinforced by Alexander suggesting that "people will not feel comfortable in their houses unless a group of houses forms a cluster, with the public land between them jointly owned by all the householders."[100]

The next stage of the design process will resolve:

- Materiality – using in-situ resources.
- More pronounced communal spaces, and use of intimacy gradients.
- Clear clusters.
- Integration with brief.

98 Zubrin and Wagner, *The Case for Mars: The Plan to Settle the Red Planet and Why we Must,* 189-190.

99 Alexander, *A Pattern Language,*610.
100 Ibid

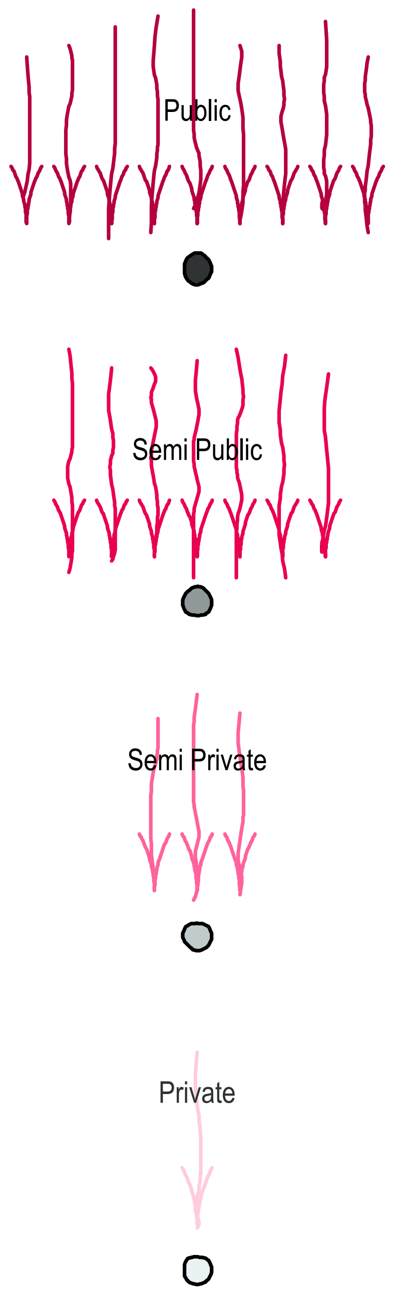


Figure 112 *Intimacy Gradient as defined by Christopher Alexander*

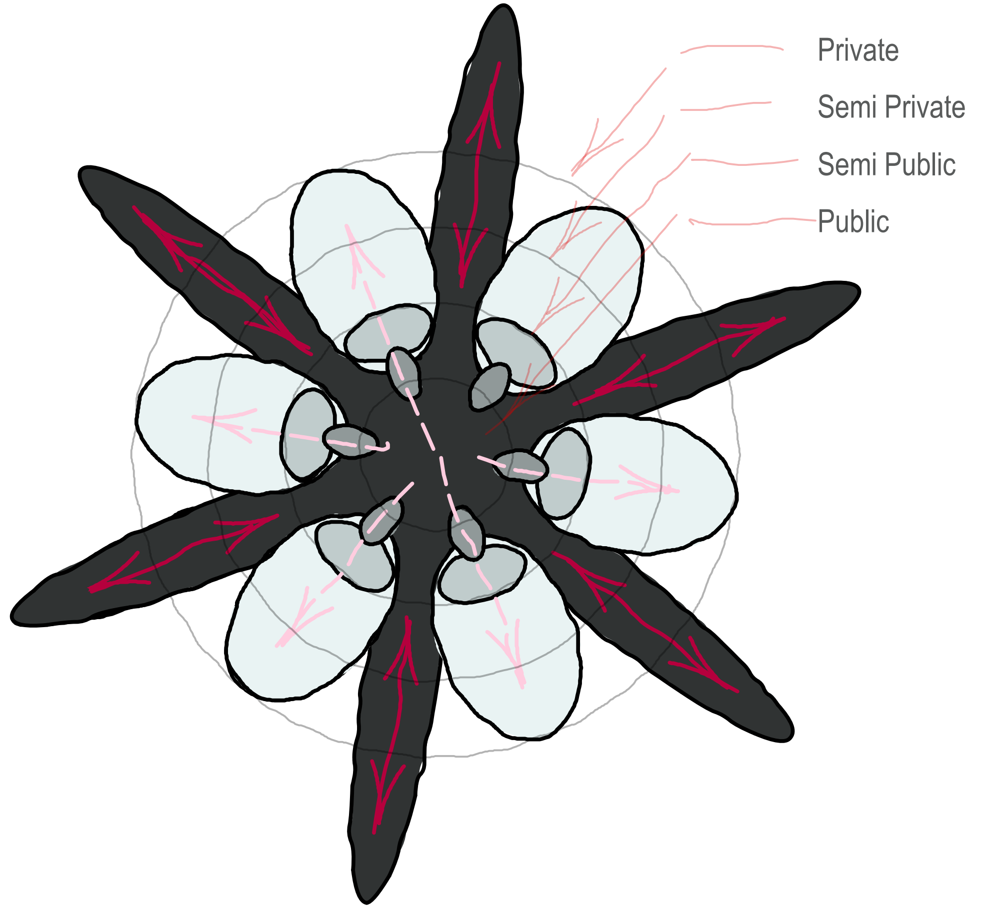


Figure 113 *Overlay of clusters and intimacy gradients - method to be applied to in the next design stage.*

8.0 Conclusion

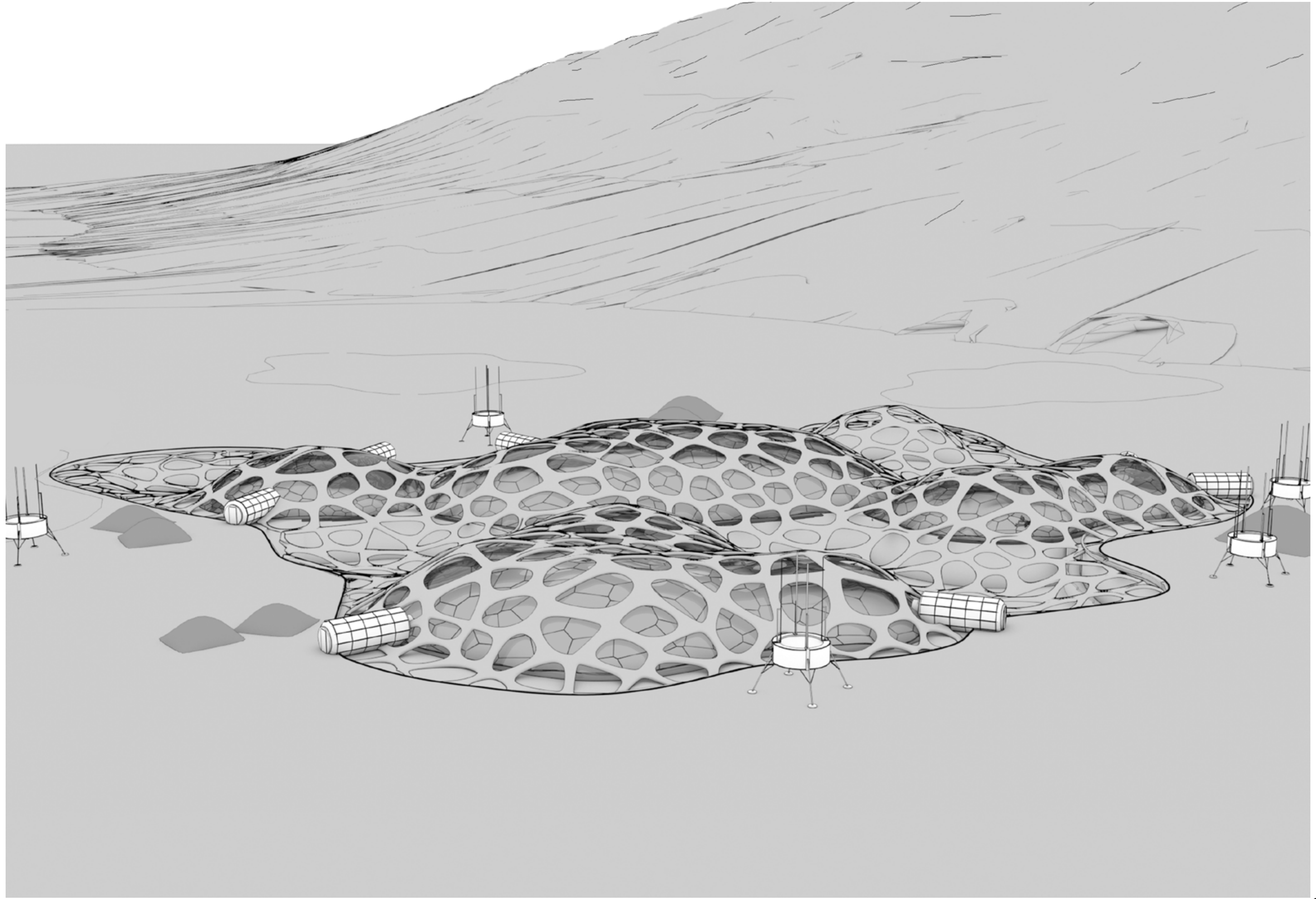


Figure 114 Previous page - Overall habitation.

8.1 Concluding Remarks

The main aim of this project was to design a permanent habitation on Mars through exploration into algorithmic master planning, 3D printing, robotics and parametric design.

Using scripts and algorithms in a world void of any built form that is Mars, appears to offer some freedom towards design. The growth and evolution of architecture is ordered using a set of rules. Ultimately these sets of rules allow for an ever growing colony.

3D printing technology offers a world of possibilities in the exploration of digital form making. This applies not only to terrestrial construction, but as this project has highlighted is particularly suited to an extra-terrestrial context. Iterations of digitally reproduced form at 1:1 scale allows designers to explore never before imagined forms and construct them to precision even in the harshest environments.

Robotics has also been utilised as a space defining tool in this research project. In an environment where the construction of spaces is extremely difficult and arduous, robotics has a significant role to play. Automation transforms the digital realm to the built realm mostly without the need for human intervention.

Using software such as Grasshopper 0.9 and Rhinoceros 5.0 enabled this project to explore the capabilities of parametric design. This project was conceived on utilising existing technologies albeit

on a larger scale and adopting some processes that are theoretical in design at this stage. Ultimately some liberties were taken in the technical aspect of this research project to ensure a conceivable outcome being achieved.

Finally, the ultimate goal was arriving at an architectural response for permanent habitation on Mars which resolves problems associated with living in isolation and in a small groups of people. It was concluded that, increasing the number of people in such a situation will result in a more psychologically friendly environment.

Architecturally, Mars One's proposes a "bare minimum" approach to permanent human living. This project attempted to create a communal living environment that is more socially inclusive. Using basic design considerations such as providing secondary circulation space, using intimacy gradients, maintaining visual connection to the landscape, maintaining daylight and normal day night cycles, might allow for a more cohesive community to successfully live on Mars.

The recent conformation of liquid water being present on the surface of Mars during the summer periods, has again sparked interest in the Red planet.[101] This new evidence suggests that Mars is in fact not completely arid as what it was imagined previously. Furthermore, where there is water there is life, the presence of liquid water offers the very real possibility that some sort of biological matter may exist on the planet. And even if it doesn't, the presence of water ultimately means the most precious resource to humans is available on the planet.

101 Ian Sample, "NASA scientist find evidence of lowing water on Mars," accessed September 29, 2015. http://www.theguardian.com/science/2015/sep/28/nasa-scientists-find-evidence-flowing-water-mars.

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11.0 Appendix A

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Figure 120 Image below 3D printed desgin model of habitation

11.1 Initial Form Finding Exploration

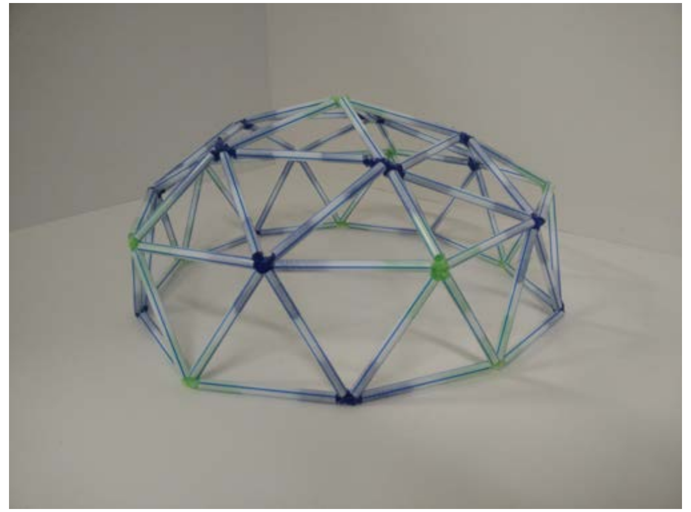


Figure 115 Image above - Straw model of a Geodesic dome.

Figure 116 Image above - Laser cut model of Dome variant

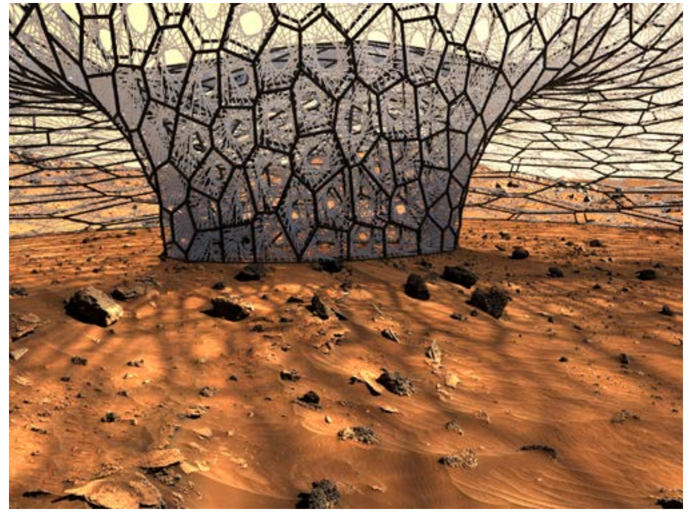


Figure 117 Initial internal view of volume exploration using tubular construction and carbon fibre filaments - subsequently superseded.

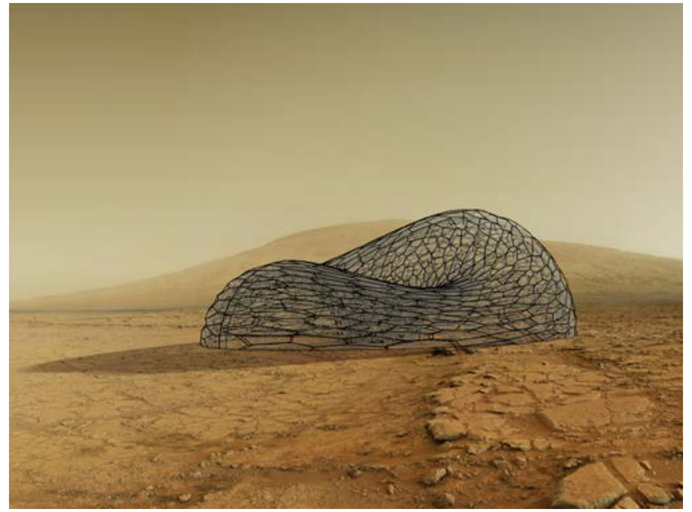
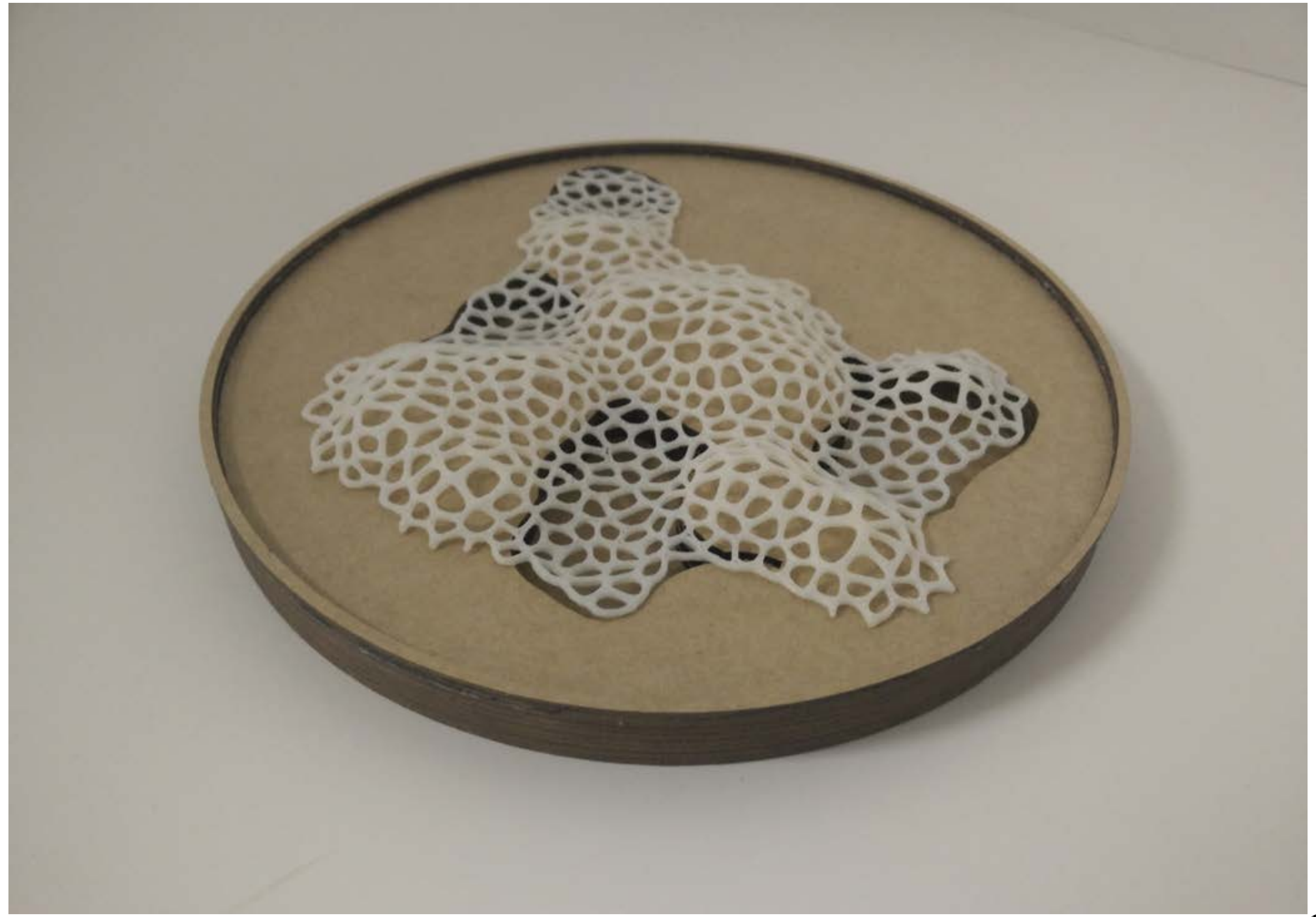


Figure 119 Initial volume exploration in context using tubular construction and carbon fibre filaments - subsequently superseded.



11.2 Scripts

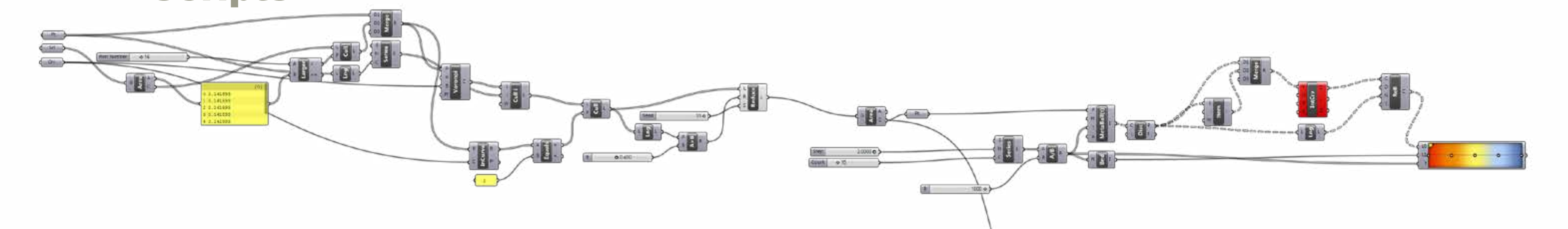


Figure 121 *Image above Grasshopper script used to generate masterplan.*

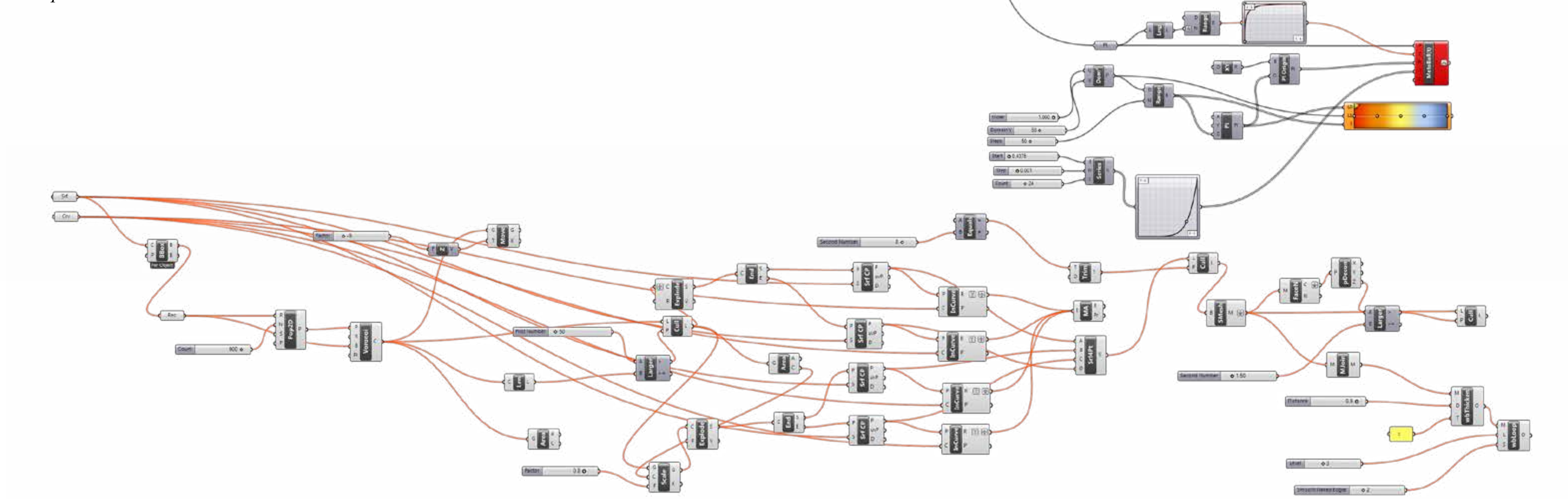


Figure 122 *Image above Grasshopper script used to generate Voronoi tessellation.*

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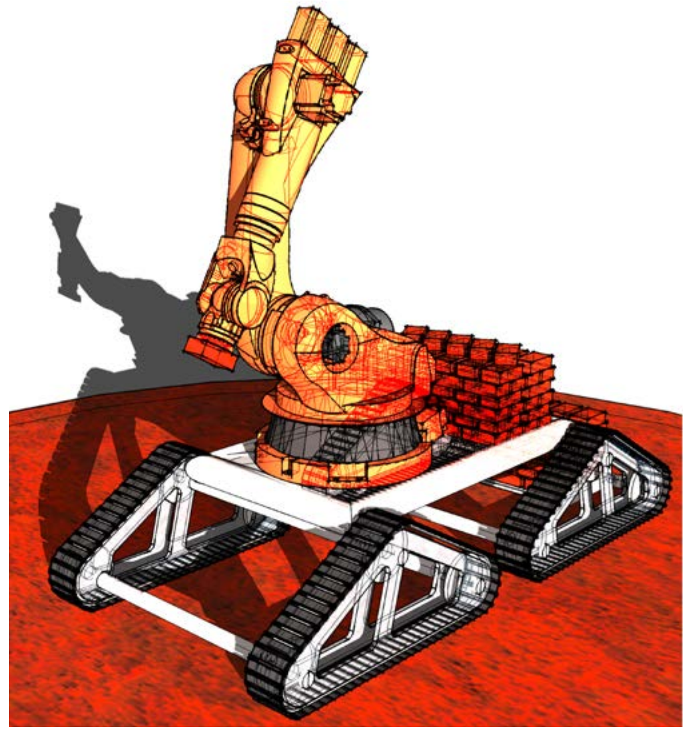
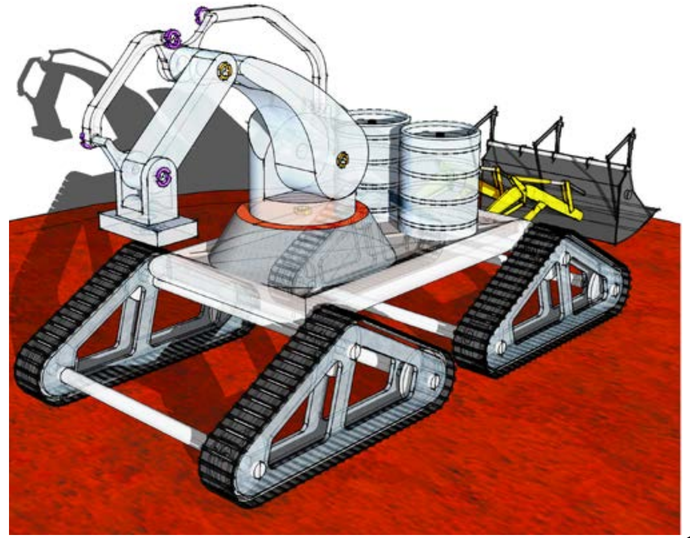
11.3 Robotic Equipment





12.0 Appendix B

Early Research Subsequently Superseded

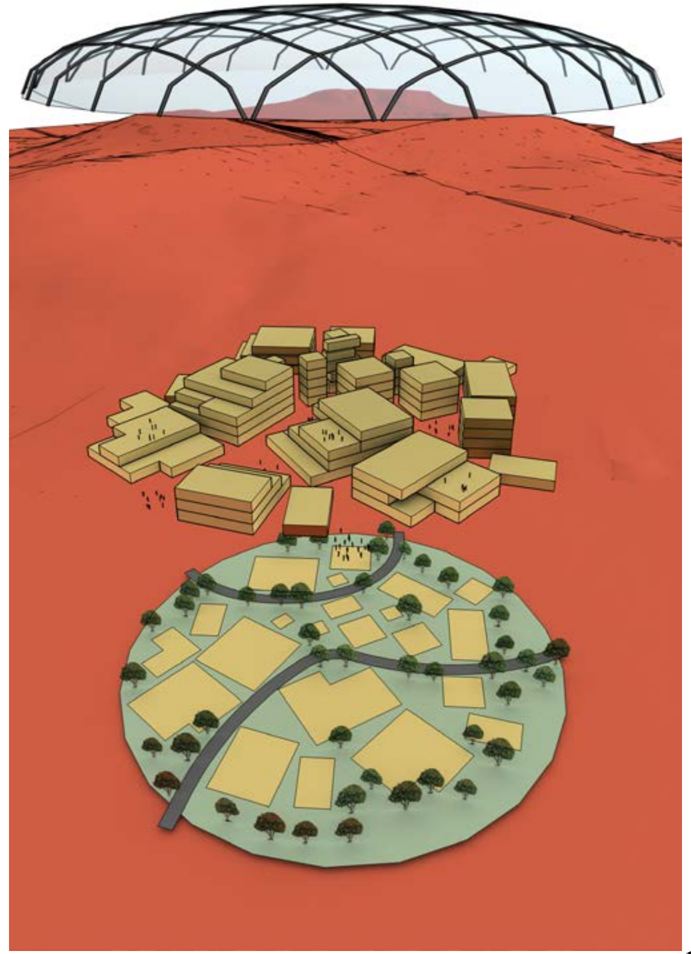


Figure 125 *Image previous page - Exploded initial design model*

12.1 Research Question

What role can architecture play in the preservation, protection and promotion of human civilisation in the event of a possible apocalyptic Earth future?

12.2 The Problem

"My Generation is the first in human history to worry whether our children and grandchildren will survive, or will have a planet worth living on."- **Jared Diamond**

The perception that our entire planet is on a whirl-wind state of irreversible self-destructive behaviour is a debated topic. However, two very significant issues in our current world climate are unquestionably time-bombs, global climate change and nuclear war.[1]

Global climate change is undoubtedly a reality and a focus of much research and speculation. Different studies conducted by various researchers have concluded if climate change is not slowed or reversed much of the world as we know it will cease to exist. Research suggests that major cities such as New York, London and Paris will become uninhabitable by 2045[2] and within the 24th century much of the world will become uninhabitable.[3]

The nuclear threat is also a very significant issue. At present a total of 15,700 nuclear weapons are in the inventories of 9 countries.[4] If an all-out nuclear war was to eventuate it would not bode well for the state of the entire planet.

The threat of asteroids hitting Earth and wiping out humanity as we know it is also a very distinct possibility, which has historical precedence. Dinosaurs once dominated the Earth were wiped out 65 mil lion years ago by an asteroid.

There are significant social issues to be addressed as well. Throughout history, human civilisations have collapsed and suffered through great depressions over the centuries. The Roman Empire's collapse. The earlier Minoan and Mycenaean civilisations which rose and achieved advanced statuses also collapsed. These rises and collapses are prevalent through all societies however varied in there geographic locations on the globe.

Aside from Europe, civilisations spread across the globe have suffered entire collapses. Mesopotamia considered the cradle of civilisation, cultivation, intricate society and urban life suffered the same consequence through the rise and fall of the Sumerians, the Akkadian, Assyrian, Babylonian, Achaemenid, Seleucid, Parthian, Sassanid, Umayyad,

1 Jared Diamond and Rebecca Stefoff, *The Third Chimpanzee* (New York: Oneworld Publications, 2014), 271

2 James Nye, "Apocalypse Now: Unstoppable man-made climate change will become reality by the end of the decade and could make New York, London and Paris uninhabitable within 45 years, claims new study," accessed July 2, 2015, http://www.dailymail.co.uk/news/article-2451604/Apocalypse-Now-Unstoppable-man-climate-change-reality-end-decade-make-New-York-London-Paris-uninhabitable-45-years-says-new-study.html.

3 Stephen Messenger, "Half of Earth Will Be Uninhabitable by 2300, Study Says," accessed July 2, 2015. http://www.treehugger.com/clean-technology/half-of-earth-will-be-uninhabitable-by-2300-study-says.html.

4 FAS Federation of American Scientists, "Status of World Nuclear Forces," accessed July 2, 2015, http://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/

and Abbasid Empire.[5]

Egypt, suffered the same fate along with Anatolia and the Indus valley civilisations. Indian Mauryan and the Gupta Empires went through the same cycle. South East Asia also suffered similar ebbs and flows.[6] However, this occurrence is not only associated and confined to the 'old world'.

The Mayan civilisation suffered a similar collapse albeit much later than the old world. Almost all of the civilisation vanished around the 8th Century AD, with virtually all of its population lost.[7] The Pacific Islands also went through collapses as well. Easter Island is one such example.

A recent study of the South Eastern Europe around 8,500 years shows that regional population growth followed a "boom and bust" pattern, through the introduction of agriculture. This study was then tested with regional climatic conditions to establish a relationship between the introduction of agriculture and climatic conditions. However, the results were inconclusive and the study suggests that the patterns may have arisen from endogenous causes. Rapid population growth driven by unsustainable farming practices may be one such cause that could have caused the pattern to emerge.[8] Regardless of the cause these patterns these cycles are real and have a 300-500 year rotation.[9]

In summary, despite the common impression that societal collapse is rare, or even largely fictional, the "picture that emerges is of a process recurrent in history, and global in its distribution"[10] and these social issues have risen from population, climate, water, agriculture and energy.[11]

Now as history teaches us and what the current global condition is the question that arises. What would happen to the human condition in the event of such a complete physical and societal collapse of human civilisation?

5 Motesharrei, Safa, Jorge Rivas, and Eugenia Kalnay. "Human and Nature Dynamics (HANDY): Modeling Inequality and Use of Resources in the Collapse or Sustainability of Societies." Ecological Economics 101 (2014): 2. Accessed July 13, 2015. http://www.sciencedirect.com/science/article/pii/S0921800914000615.
6 Ibid, 2.
7 Ibid, 2

8 Shennan, Stephen, Sean Downey, Adrian Timpson, Kevan Edinborough, Sue Colledge, Tim Kerig, Katie Manning, and Mark Thomas. "Regional Population Collapse Followed Initial Agriculture Booms in Mid-Holocene Europe." Nature Communication, 2013, 1. doi:10.1038/ncomms3486.
9 Motesharrei, Safa, Jorge Rivas, and Eugenia Kalnay. "Human and Nature Dynamics (HANDY): Modeling Inequality and Use of Resources in the Collapse or Sustainability of Societies." Ecological Economics 101 (2014): 3. Accessed July 13, 2015. http://www.sciencedirect.com/science/article/pii/S0921800914000615.
10 Joseph A Tainter, *The Collapse of Complex Societies.* (Cambridge, Cambridgeshire: Cambridge University Press, 1988), 5.

11 Nafeez Ahmed, "Nasa-funded Study: Industrial Civilisation Headed for 'irreversible Collapse'?" accessed July 13, 2015. http://www.theguardian.com/environment/earth-insight/2014/mar/14/nasa-civilisation-irreversible-collapse-study-scientists.

12.3 The Solution

"Without the belief that we will continue to grow and overcome the pains of social chaos as we mature as a species, we might as well not have any faith at all. I'm not talking religion ... but simply the same belief that we will survive just as much as the sun will rise the next day," – ***Professor Stephen Hawkins***

In order to maintain the human condition even in the face of calamity it must be preserved. The human condition can be described as "the characteristics, key events, and situations which compose the essentials of human existence, such as birth, growth, emotionality, aspiration, conflict, and mortality."[12] Which can be further analysed from the perspectives of religion, philosophy, history, art, literature, sociology, biology and psychology. Preservation in this case refers to the management of collections of physical resources so that current and future generations can access them. Presently an analogy can be drawn between technology and preservation. This analogy looks at the ability to back-up ones digital information to an "invisible cloud" or other methods stored off-site or in a fire safe. More often than not in the event of a device failure, natural disasters or other catastrophic events, a user can retrieve all of their digital footprints. A similar, back-up strategy can be thought of as a solution to the scenario outlined. Creating a repository of valuable resources, in order to preserve the human condition. This storehouse would provide the basis of continual human survival, even if humanity is threatened with complete extinction.

This would create a back-up of everything that the world, knows and believes. The back-up would include scientific knowledge, great religious texts to comic books, seeds and agricultural samples, music, art and the humanities, human and animal genetic records and samples . EVERYTHING. This collection would become an ongoing, living record of humanity and all it entails as a global civilisation. Once collected (which would take a generation or more to collect) this backup must be updated regularly to keep current. These collections than must be stored on an off-site location, someplace not vulnerable to being damaged or destroyed together with the original.

This method will allow the off-site backup to act as a catalyst to allow for the human civilisation to rebuild or continue in its foreign environment. A back up would ensure that human society will not completely vanish.

As mentioned in the previous chapter, physical and social issues have in the past caused global catastrophic events to occur. However, it is highly unlikely that humanity will be completely lost.

12 "Human Condition," *Wikipedia,* last modified 1st September 2015. https://en.wikipedia.org/wiki/Human_condition

Humans in particular are extremely resilient. But in the event of an isolated number of people surviving, they would struggle to rebuild and much of the world’s achievements would be completely lost.

Therefore, mankind’s collective memory must be preserved. Mars seems to provide a suitable platform to create such an endeavour. This research project will attempt to explore the feasibility of this capacity. Housing the back-up on another planet ensures that if either one establishment collapses for whatever reason, a continual blueprint for humanity endures.

The proposed preservation will happen by protecting resources by saving them from the harsh effect of the environment. The harsh environment in this case refers both to the harsh planetary conditions of Mars and the inevitable consequence of the harshness of planet Earth created through social and physical collapse.

12.4 Precedents

12.4.1 Svalbard Global Seed Vault

Located about 1300 km south from the North Pole on the Norwegian island of Spitsbergen is the Peter w. Sodermann designed secure seed bank. This facility is designed with the sole purpose of housing and storing duplicate samples of various plant seeds from all over the world. In doing so, the seed vault aims to prevent total loss of seeds in other gene banks in the event of regional or global crisis.

The Svalbard Vault serves as a back-up for the world’s 1,750 seed banks. To show the need for it the Philippines’ national seed bank was destroyed by fire in January 2012 while, Afghanistan and Iraq have been completely lost.[13] By the end of its first year the facility housed 490,000 different variety of seeds, amounting to more than 200 million individual seeds.[14]

The location of the seed vault was considered ideal because the area lacked tectonic activity and had permafrost, which would aid in preservation. Refrigerating the vault at internationally recommended temperature of -18°C, further aids to preserve the seeds. In the event of equipment failure it will take several weeks before the seeds will warm up to -3°C of the surrounding bedrock.[15]

This project is an example of rigorous investigation and resolution of the pragmatics of long term preservation. The project will be further analysed under its functional parameters and conclusions can be drawn from this example, which will aid in the process of designing storage facilities on the Martian surface.

Possible Advantages

• Low temperatures provide for long term preservation.

• Example of the need for preservation.

• 500 seeds sealed in an aluminium packet provides for best storage.

• Area of reduced seismic activity ensures protection from geologic activity.

• Area of reduced rain, winds to help mitigate lateral forces.

Possible Disadvantages

• Spatially and functionally only caters to preservation of seeds.

• Fundamental problem lies in that if this backup is destroyed along with the others, it doesn’t serve any purpose.

Thomas Heatherwick’s Seed Cathedral is an

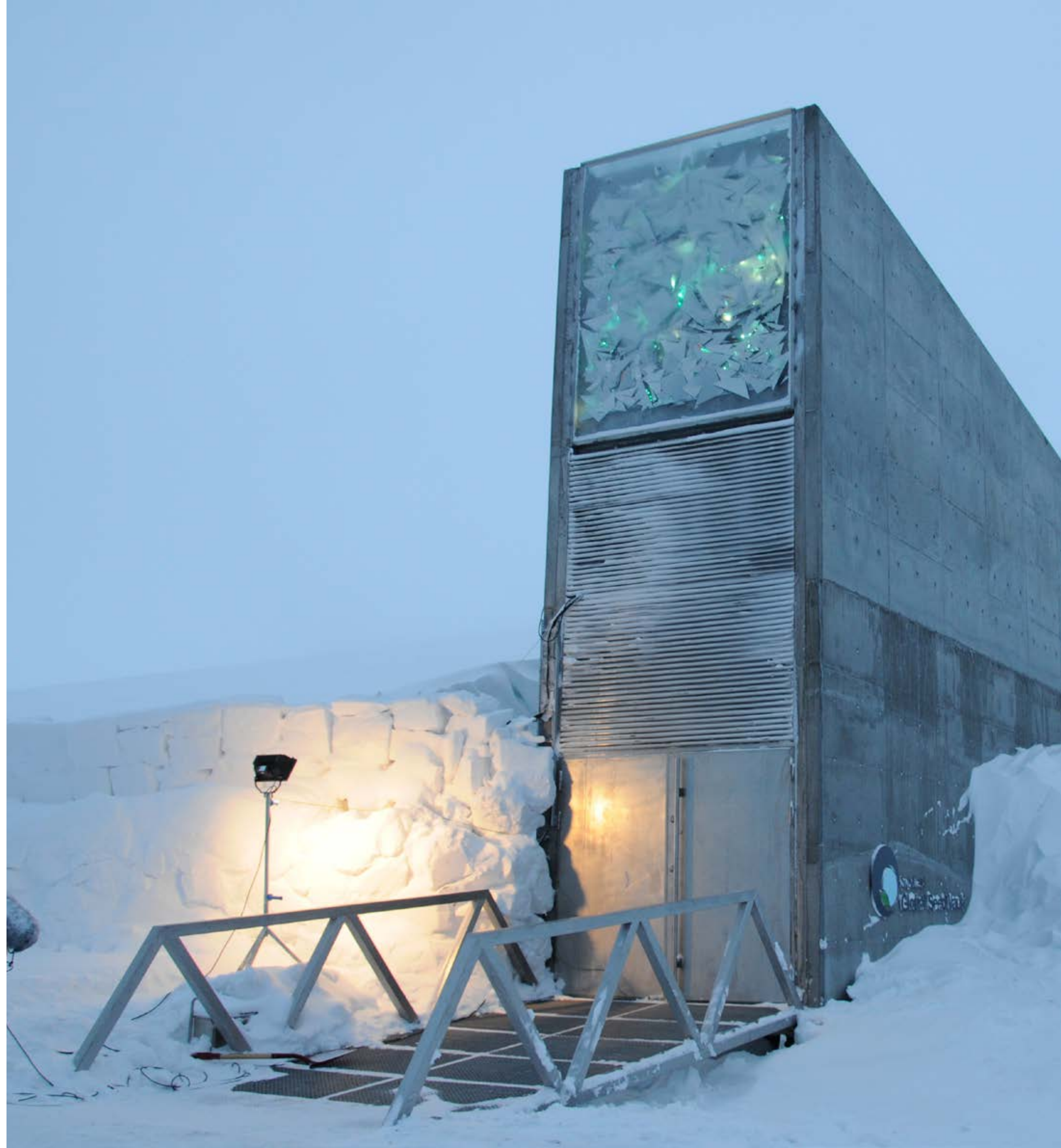


Figure 126 *Image right - Svalbard’s Global Seed Vault*

13 The Economist, “Banking against Doomsday,” accessed July 20, 2015. http://www.economist.com/node/21549931.

14 Bryan Walsh, “The Planet’s Ultimate Backup Plan: Svalbard,” accessed July 20, 2015. http://content.time.com/time/health/article/0,8599,1882288,00.html.

15 Daniel Charles, “A ‘Forever’ Seed Bank Takes Root in the Arctic,” accessed July 20, 2015. http://www.sciencemag.org/content/312/5781/1730.2.full.

12.4.2 UK Pavilion at Shanghai Expo 2010

example of an architectural intervention that exhibits the content of its purpose as a façade. This project aims to signify seeds as a crucial part of the ecology of the planet and fundamental link to human nutrition and health.[16]

The cathedral is a modest 15 meter wide and 10 meter high box. From each of the surface a 7.5 meter long clear acrylic rod extends through the wall and into the box interior. Each of these rod house seeds. 60,000 such rods penetrate all the façades of the pavilion housing a total of 250,000 different seeds.[17]

The pavilion was designed under the theme "Better City, Better life" – which inspired the architects to use seeds as the ultimate symbol of unfulfilled potential and future promise.[18]

The seeds of the pavilion are sourced from the Millennium Seed Bank, which has been aiming to collect and preserve up to 25 percent of the world's wild plant species. Although the seed bank project is well known, few people have actually seen it. This project promotes preservation through making an architectural statement.

The project uses elements of movement in architecture and lighting. Both these elements could induce a very interesting angle to Martian architecture and can be manipulated such that to provide extraordinary spatial qualities. This project

16 Thomas Heatherwick and Maisie Rowe. "UK Pavilion." In *Thomas Heatherwick Making*, (London: Thames & Hudson, 2012), 449.
17 Ibid

18 Ibid

Possible Advantages

• Example of how the function of a space can also deduce to the spatial quality of the space. That is the seeds are not just tucked away in storage but rather promoted.

• Example of how spatial conditions can be controlled from

Possible Disadvantages

• Only functions as a seed vault, could it do more?

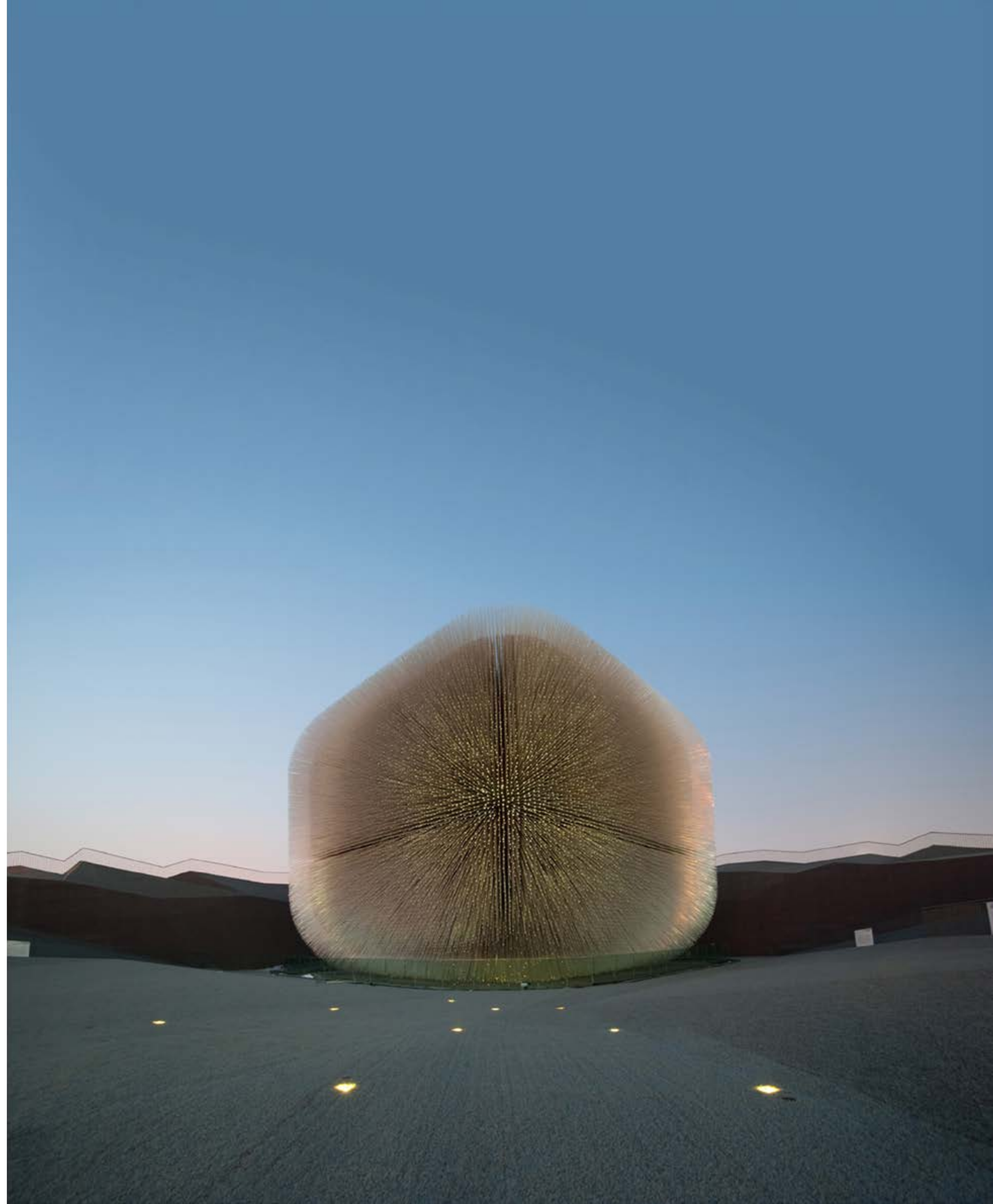


Figure 127 *Image right - Seed Cathedral*

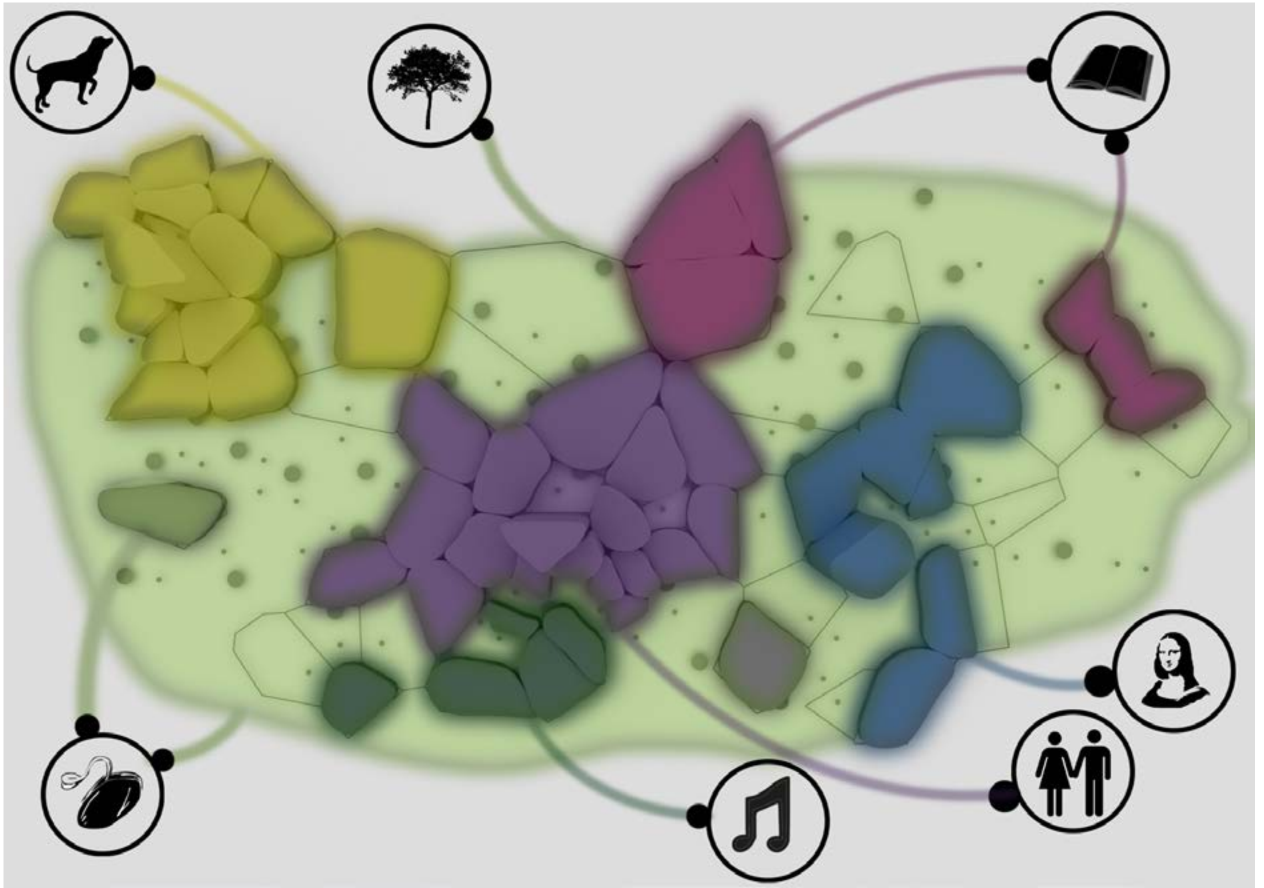


Figure 128 *Image above - Early planning excerise.*

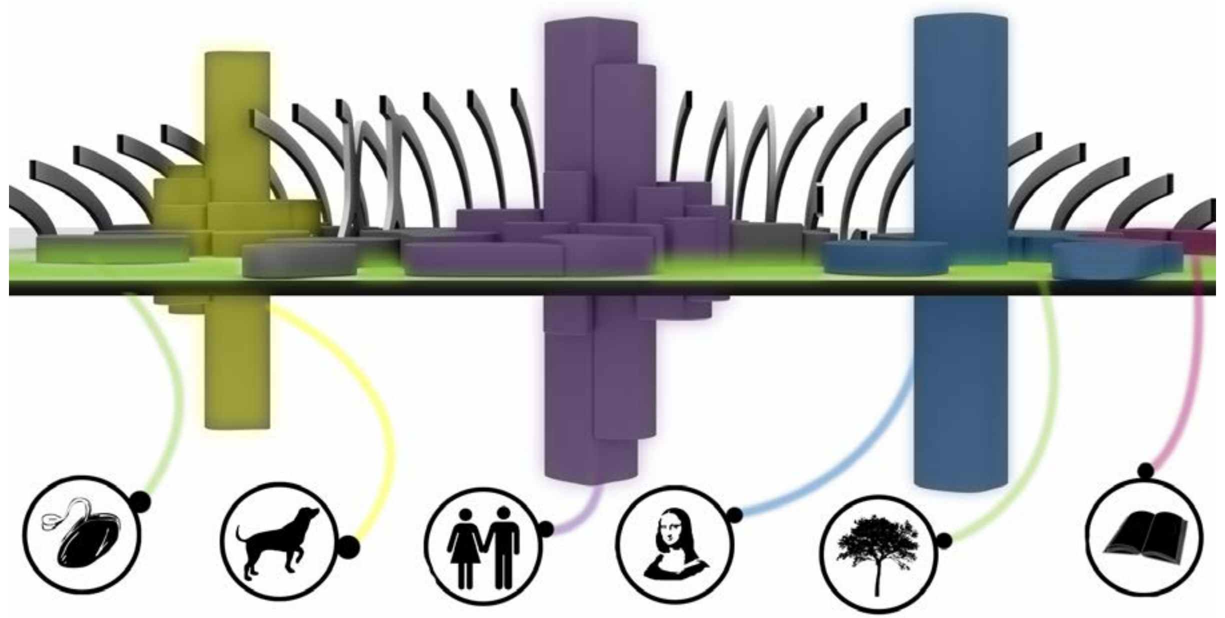
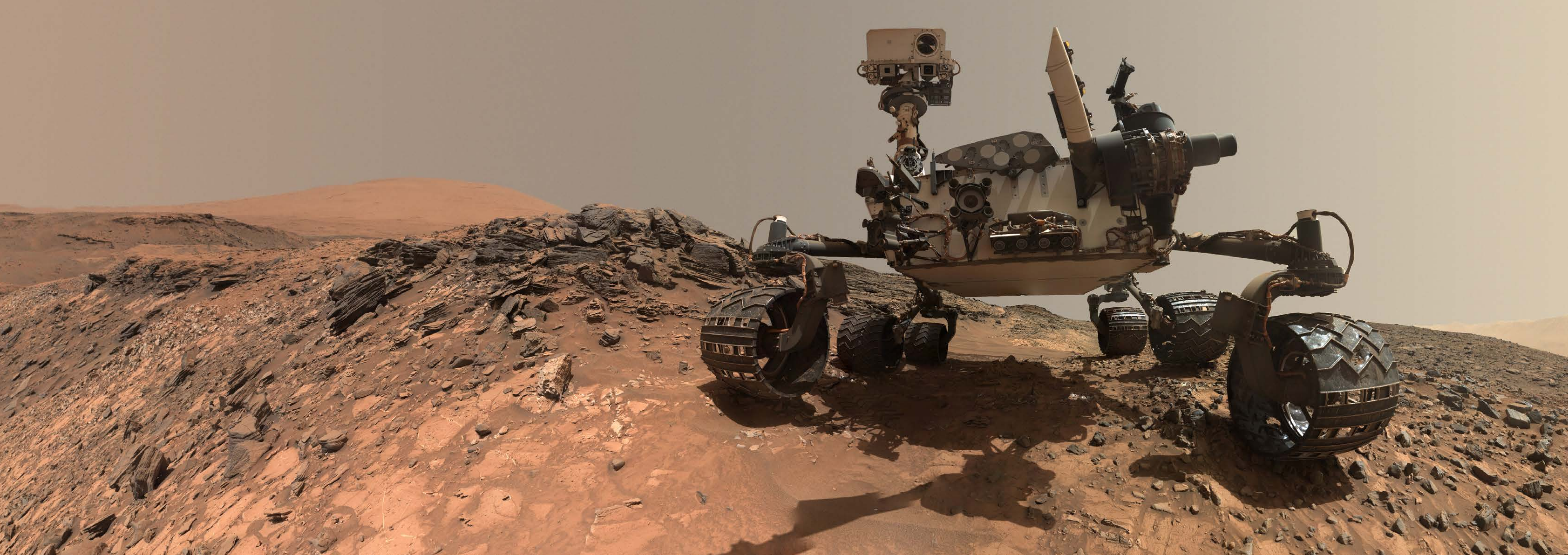
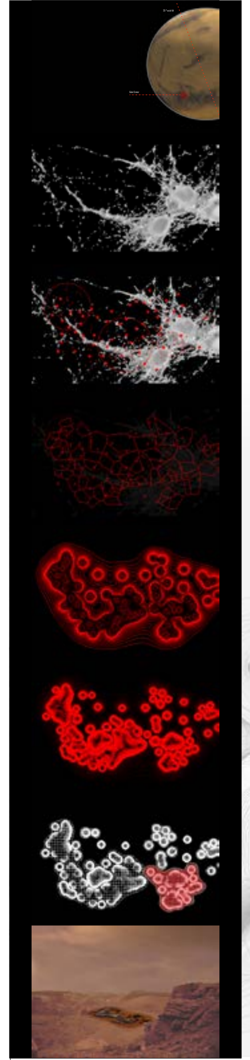


Figure 129 *Image above - Early planning excerise.*

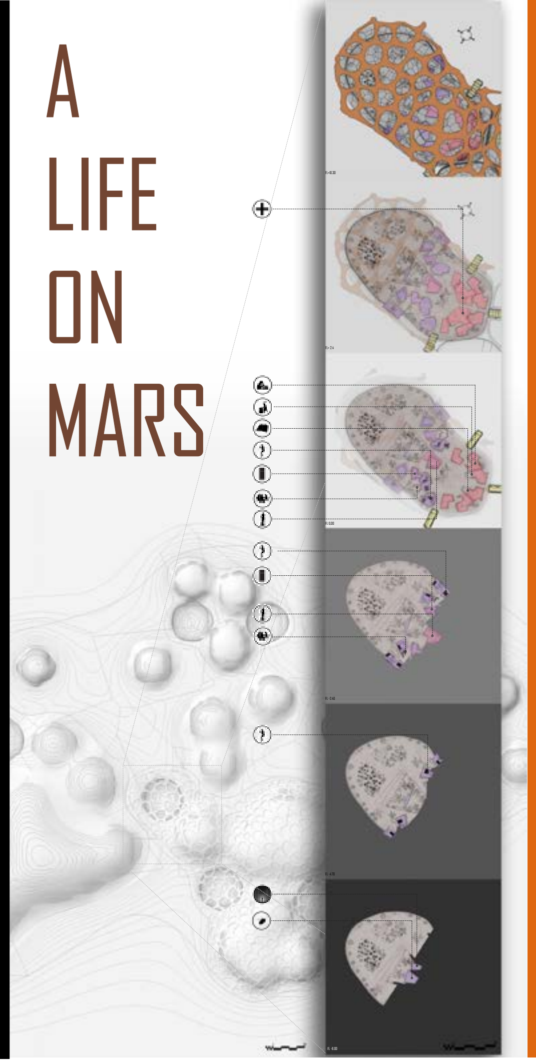
Figure 130 *Image last page - Low-angle Self-portrait of NASA's Curiosity Mars Rover*

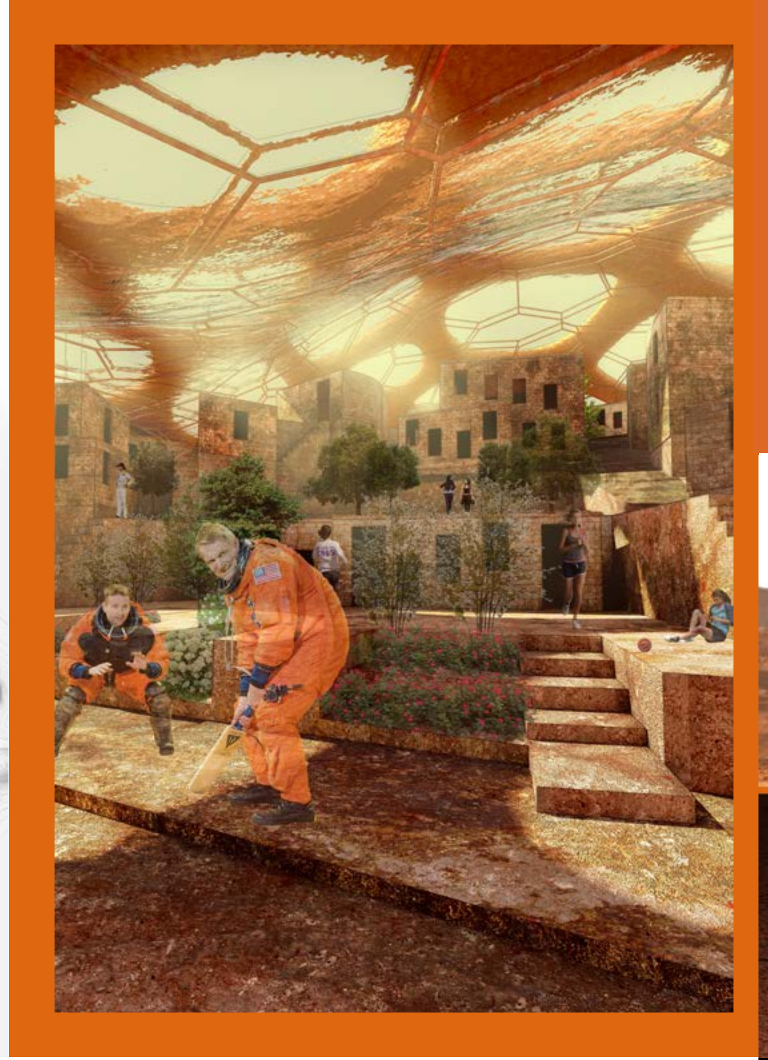


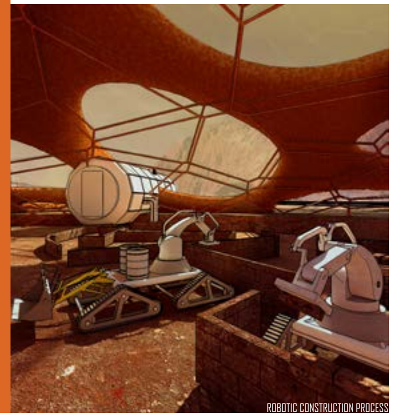
13.0 Final Presentation



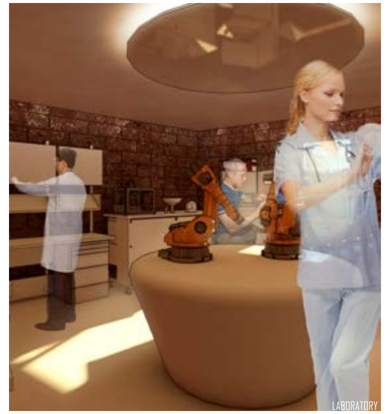
A LIFE ON MARS





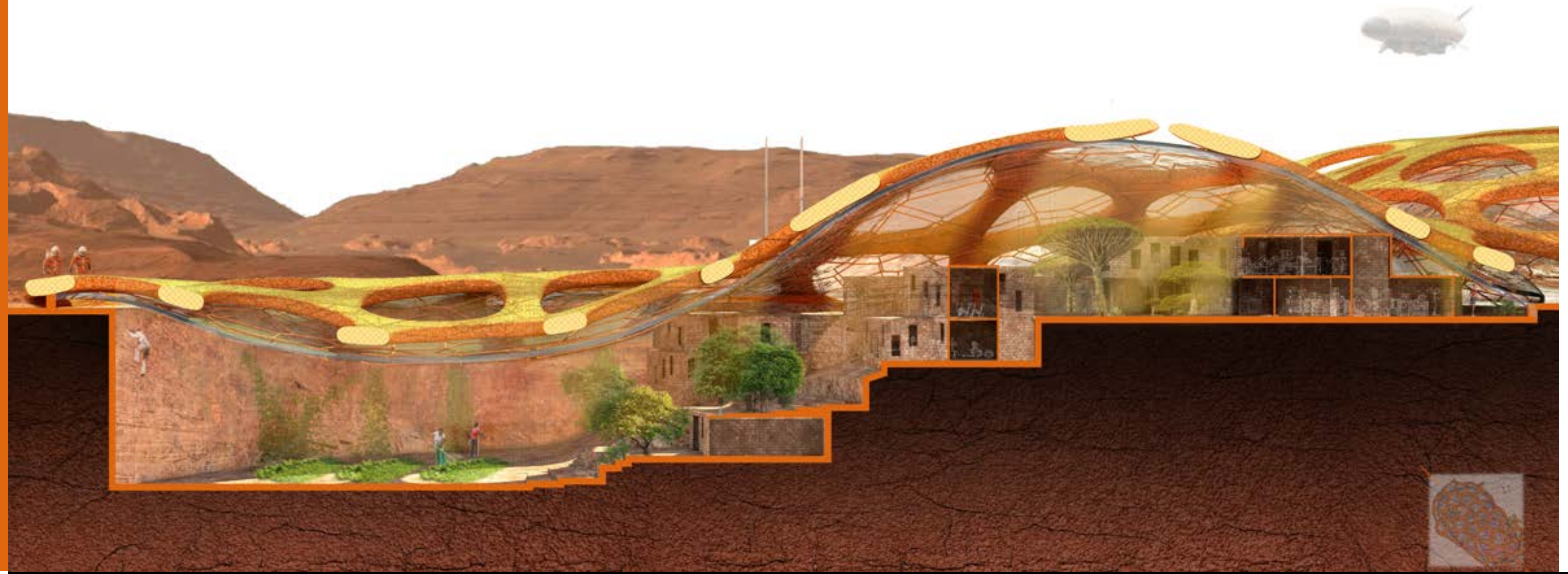


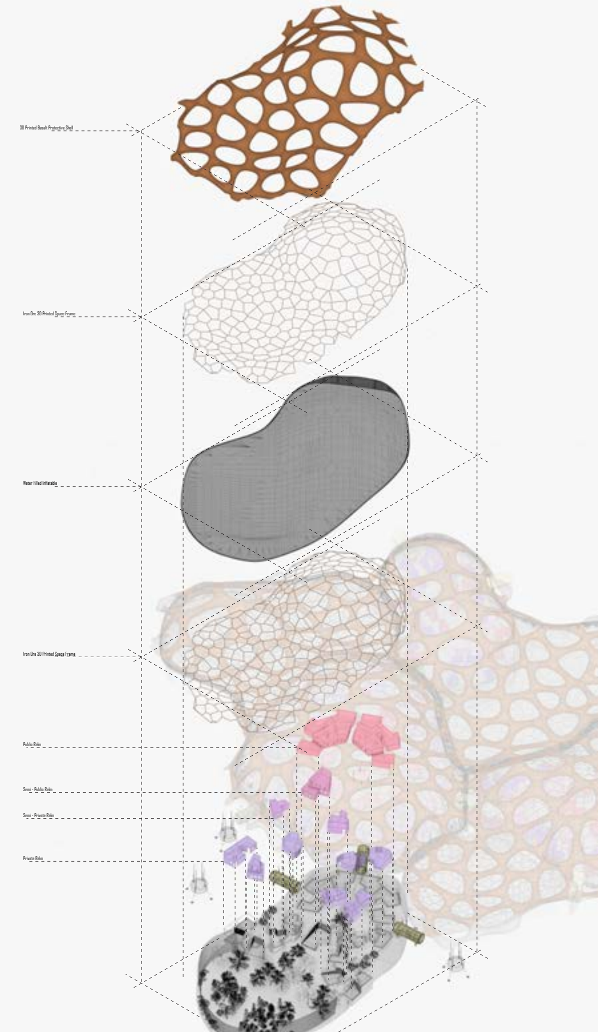
ROBOTIC CONSTRUCTION PROCESS



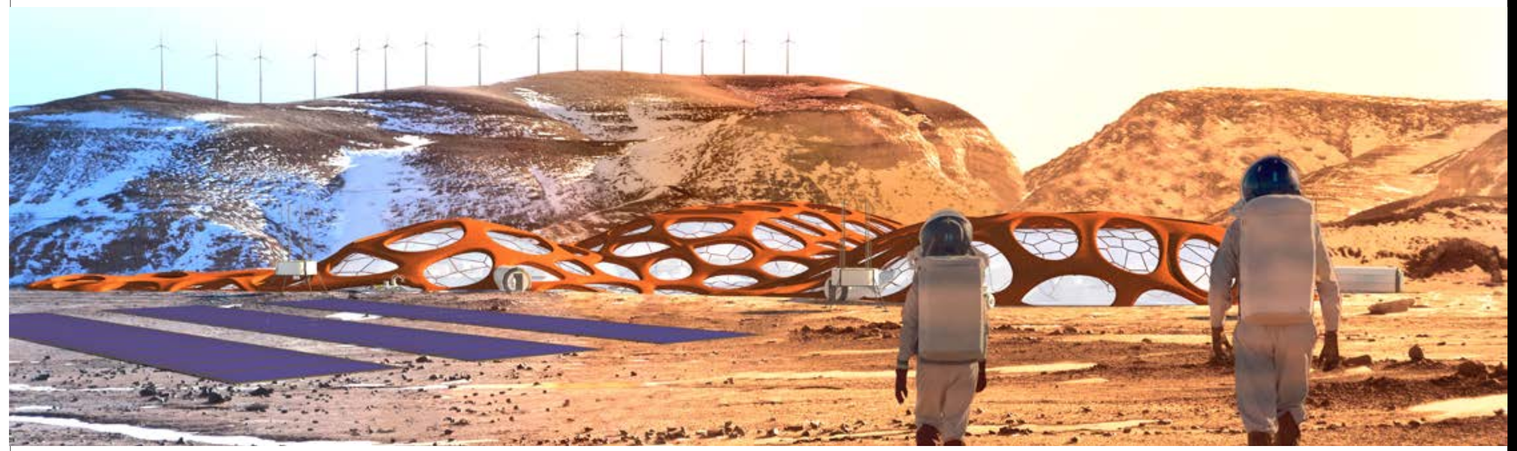
LABORATORY

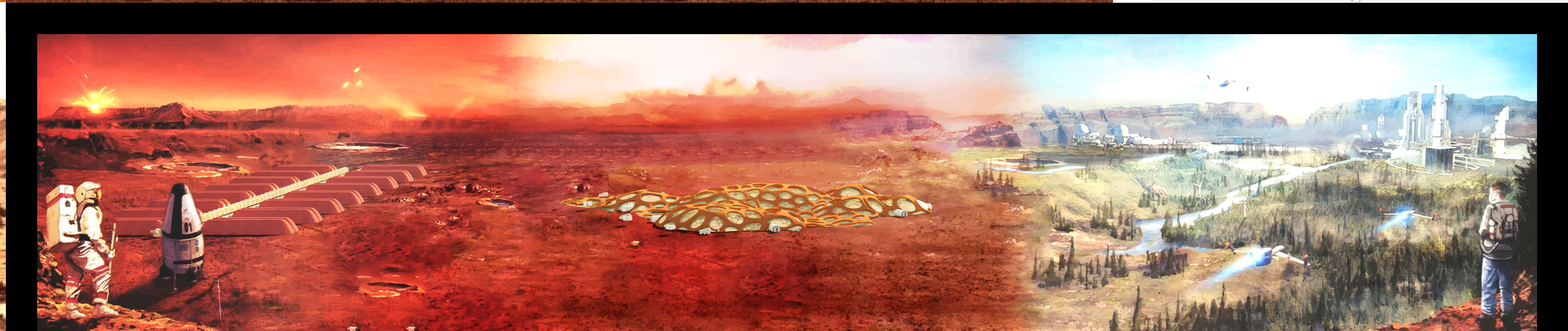
COMMUNAL LIVING SPACE





EXPLODED AXONOMETRIC





TIME LAPSE FOR A POTENTIALLY TERRRAFORMED MARS